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ETHANOL PRODUCTION FROM WHEAT - VALUE OF CO-PRODUCTS FOR ANIMAL PRODUCTION

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Ethanol Production from Wheat – Value of Co-products for Animal Production

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a) Summary

Our overall objective was to assist the ethanol and the livestock sectors in Saskatchewan with the introduction and incorporation of wheat-based dried distillers' grains with solubles (DDGS) into the animal feeding sector and for feed export. In order to optimize the use and value of wheat-based DDGS in the animal feeding sector, we require reliable nutritional assessment of DDGS, feeding value and feeding recommendations for the various classes of livestock. This project developed a detailed nutritional profile of DDGS from ethanol production for use by livestock nutritionists, feeding strategies for backgrounding and finishing beef cattle and overwintering beef cows, and recommendations for the use of DDGS in poultry diets.

Optimizing the use and value of DDGS will not only help to ensure viability of the ethanol industry, but will also present a significant opportunity to concurrently grow the Saskatchewan livestock industry in a sustainable manner.

This project is separated into distinct experimental projects which are detailed below. Based on input from these sub-projects, the collective objectives of the overall project are as follows:

1. Characterization of DDGS feeding value through established chemical and in vivo/in vitro methods including near infrared spectroscopy, and creation of a DDGS database that can be used to determine and improve predictability of feeding value;
2. To complete a preliminary assessment of the functional properties of proteins immediately after the liquefaction, distillation and DDGS drum drying steps of ethanol production;
3. To develop nutritional strategies that optimize the use of DDGS in low cost backgrounding programs for feeder cattle and for grazing and overwintering beef cows;
4. To develop nutritional strategies that incorporate DDGS into finishing rations that have reduced potential for acidosis and other digestive problems.

5. To determine the digestible energy and amino acid content of wheat DDGS and establish feeding recommendations for wheat DDGS in broiler diets.

Information gathered during the course of this project has laid a solid foundation for future work on, not only the variability in nutritional and functional characteristics of ethanol co-products, but also how processing conditions influence their end use in the livestock feeding sector. The use of DDGS as a supplement for beef cows potentially has both nutritional and economic benefits. However, the effectiveness of using DDGS as a supplement for beef cows should be assessed based on the feeding situation and commodity price. It was found that wheat-based DDGS are a good source of energy and protein when fed to both backgrounding and finishing cattle. However, beef producers feeding distillers grains as an energy and protein source will need to consider the potential for elevated nitrogen and phosphorus levels in manure and a manure management plan will be required to effectively use these nutrients for plant growth. Although digestibility of DDGS in poultry diets has been found to be variable, it has been demonstrated that relatively high levels of wheat DDGS can be successfully incorporated into broiler diets.

Project Reports

1) Characterization of nutritional quality and economic value of DDGS – Chemical Characterization

b) Introduction

Dried distillers grains with solubles (DDGS) are a byproduct of fermentation during bio-ethanol production. As a result of the government policies to stimulate the expansion and consumption of bio-fuels, the number of bio-ethanol plants has increased in Western Canada. Although the bio-ethanol industry in this part of the country is wheat based, the fluctuation in the price of wheat has forced bio-ethanol companies to include corn in the feedstock for bio-ethanol processing, consequently not only pure wheat DDGS but also blend (wheat/corn) DDGS is available.

While the nutritional value of corn DDGS for ruminants has been extensively documented (Cromwell et al. 1993; Spiehs et al. 2002; Shurson 2005; Kleinschmit et al. 2006; Rosentrater and Muthukumarappan 2006; Kleinschmit et al. 2007; Martinez-Amezcua et al. 2007; Stein and Shurson 2009), detailed information on wheat DDGS and wheat/corn blend DDGS is scarce and not recent (Dong and Rasco 1987a; Boila and Ingalls 1994a, 1994b; Nyachoty et al. 2005; Widyaratne and Zijlstra 2006; Penner et al. 2009). Thus, a database on chemical profile, protein and carbohydrate fractions, and energy values needs to be created in order to proceed with feeding recommendations for ruminants. Likewise, it is important to detect plant to plant variation and how this inconsistency in the product affects nutrient supply and consequently animal performance. To produce DDGS suitable for export and marketing, and for livestock industry within Canada, there is an urgent need for this information. So far, little research has been conducted to determine the magnitude of the differences in the nutritive value among wheat DDGS, corn DDGS and blend

DDGS (particular blend DDGS), and between wheat DDGS originated at different bio-ethanol plants in Canada.

In addition to product inconsistency, the methodology used in the nutritive characterization is crucial in order to avoid misformulation of the ration and diminished animal productivity. In the estimation of energy values, NRC (2001) describes a chemical approach in which the equations for truly digestible nutrient are based on the chemical composition of natural feeds (Weiss et al. 1992). Yet, the energy values of a feedstuff are not chemical constituents. Thus, it is a question whether this chemical approach described by NRC 2001 can accurately estimate energy values of DDGS. A biological approach, such as *in vitro* and *in situ* incubation, is considered a superior predictor of truly digestible nutrients (Robinson et al. 2004; Yu et al. 2004). The method preferred for most researchers, and also suggested by NRC 2001, is the 48 h *in vitro* incubation; however, inflated results for feeds with a high content of soluble sugars have been reported (Seker 2002). For this reason, and because of the greater similarity to real animal conditions, an *in situ* assay (48 h incubation) provides the best estimation of the total tract digestion, and consequently truly digestible nutrients and energy values (Tamminga et al. 1994; Yu et al. 2003a; Yu et al. 2004). To date, there is no information on the relationship of the NRC 2001-chemical approach and the *in situ* assay-biological approach that clarifies the accuracy of NRC 2001-chemical approach on the prediction of energy values for DDGS.

The chemical profile has been used as a method to estimate the potential digestibility of feedstuffs. While a strong negative relationship between ADICP content and protein degradability is well established in forages (Goering et al. 1972; Yu and Thomas 1976; Van Soest and Mason 1991a), moderate (Nakamura et al. 1994a) or no correlation (Klopfenstein 1996) have been found in distillers grains. Likewise, NRC (2001) uses acid detergent lignin (ADL) to predict potential neutral detergent fiber (NDF) digestibility. In order to acquire the best DDGS for livestock, more information on the use of chemical profile as predictor of potential digestibility of DDGS is required.

The objectives of this study were 1) to determine the effect of DDGS type and bio-ethanol plant on chemical profile, mineral concentrations, protein and carbohydrate fractions, and energy values; 2) to elucidate the validity of the NRC 2001 chemical approach in the determination of energy values for DDGS; and 3) to determine the effect of DDGS type and bio-ethanol plant on in situ rumen degradability of DDGS components and test the relationship between chemical profile and rumen degradability. In addition, these parameters were studied in feedstock grains as opposed to their derived DDGS product. The final aim was to provide detailed information on the nutritive value of wheat DDGS, corn DDGS and blend DDGS in order to assist nutritionists in designing low cost, efficient feed programs in Canada.

c) Methods

i) Wheat DDGS, corn DDGS and blend DDGS and original cereal grains (corn and wheat)

During May to December in 2007, three to five batches from each of wheat DDGS, blend DDGS (wheat:corn=70:30), and wheat samples were collected from two bio-ethanol plants (SK-Plant 1 and SK-Plant 2) located in western Canada. Both plants used local wheat feedstock for bio-ethanol production. During the same time frame, corn DDGS and corn samples produced by a bio-ethanol plant in North Dakota were obtained through Federated Co-Op Ltd, Saskatoon. Due to cold climate conditions, western Canada does not produce large amounts of corn and corn DDGS; however, corn DDGS and corn samples were used as reference samples for comparison with wheat and wheat DDGS.

ii) Rumen *in situ* assay

A rumen *in situ* assay was performed in order to measure rumen degradability and estimate truly digestible nutrients (tdNDF, tdCP, tdFA, tdNFC). Prior to ruminal incubation, samples were processed using a Sven Roller Mill (Apollo Machine and Products Ltd., Saskatoon, SK). The roller gap was adjusted to a size of 0.203 mm in order to equalize the particle size of all samples. Three Holstein dry cows fitted with a rumen cannula (Bar Diamond Inc, Parma, ID, USA) with an internal diameter of 10 cm were used in this study. The cows were individually fed twice daily at 0800 and 1600 according to the nutrient requirement defined by NRC (2001) at a maintenance level (See Appendix Table 8.1). The animals were cared for in accordance with the guidelines of the Canadian Council on Animal Care (CCAC 1993). Ruminal degradability of dry matter (DDM), organic matter (DOM), crude protein (DCP) and neutral detergent fiber (DNDF) at 24 and 48 h incubation, as well as ruminal degradability of total fatty acids (DFA), non-fiber carbohydrates (DNFC) and neutral detergent insoluble crude protein (NDICP) at 48 h incubation, were determined by *in situ* method (Yu et al. 2000) using nylon bags with a pore size of 40 microns. The 24 and 48 h incubation times were based on the NRC-2001 suggestion in energy estimation (48 h) and the previous published report (Yu et al. 2000). Each treatment was randomly assigned to the cows for two runs. After incubation, the bags were removed from the rumen and rinsed under a cold stream of tap water to remove excess ruminal contents. The bags were washed with cool water without detergent and subsequently dried at 55°C for 48 h. Dry samples were stored in a refrigerated room (4°C) until analysis. The residues were ground through a 1-mm screen (Retsch ZM-1, Brinkmann Instruments (Canada) LTD, Ontario) for chemical analysis.

iii) Chemical analysis

All samples for chemical analysis were ground through a 1 mm screen. Dry matter (AOAC 930.15), ash (AOAC 942.05), crude fat (CFat) (AOAC 954.02) and crude protein (CP, AOAC 984.13) contents were analyzed according to the procedure of the AOAC (1990). For the starch analysis, samples were ground to 0.5 mm and analyzed using the Megazyme Total Starch Assay Kit and by the α-amylase/amyloglucosidase method (McCleary et al. 1997). Acid detergent fiber (ADF), neutral detergent fiber (NDF) and acid detergent lignin (ADL) were analyzed according to the filtration

method (Van Soest et al. 1991b). Alpha-amylase without sodium sulfite was used prior to neutral detergent extraction. The N adjusted NDF (NDFn) was calculated as NDF-NDICP. The acid (ADICP) and neutral detergent insoluble crude protein (NDICP) values were determined (Licitra et al. 1996). The NPN content was analyzed by precipitating of true protein with tungstic acid (samples were soaked into water with 0.3 M Na_2WO_4 for 30 minutes) and calculated as the difference between total N and the N content of the residue after filtration (Licitra et al. 1996). Total soluble crude protein (SCP) was determined by incubating the sample with bicarbonate-phosphate buffer and filtering through Whatman #54 filter paper (pore size = 20 - 25 μm) (Roe et al. 1990). The non-structural carbohydrates (NSC) including starch, sugars, organic acids, and other reserve carbohydrates such as fructan were estimated by non-fibre carbohydrates and calculated (Grings et al. 1992). The carbohydrate (CHO) and true protein, hemicellulose, and cellulose were calculated (Van Soest et al. 1991b). Calcium (Ca) (AOAC 927.02) concentrations were determined by atomic absorption spectroscopy (Model Perkin Elmer 2380, Norwalk, CT) and phosphorus (P) (AOAC965.17) concentrations by spectrophotometry (Model Pharmacia LKB Biochrom Ltd, Ultroscope III, Cambridge, UK) according to the procedures of the AOAC (1990). Sulphur (AOAC 935.13) analysis was carried out by inductively couple plasma-optical emission spectrometer (Model Perkin Elmer Optima 4300 DV ICP-OES, Waltham, MA) at ALS Laboratory Group, Saskatoon, SK, Canada according to the procedures of the AOAC (1990). All samples were analyzed in duplicate and repeated if error was in excess of 5%.

iv) Partitioning protein and carbohydrate fractions

The crude protein and carbohydrate (CHO) subfractions were partitioned according to the Cornell Net Carbohydrate and Protein System (CNCPS) (Sniffen et al. 1992; Chalupa and Sniffen 1994). The characterization of the CP fractions as applied in this system is as follows: fraction PA is non-protein N (NPN), fraction PB is true protein (TP), and fraction PC is unavailable protein. Fraction PA is rapidly degradable with an assumed degradation rate to be infinity. Fraction PB is further divided into three fractions (PB1, PB2, and PB3) that are believed to have different rates of degradation in the rumen (Sniffen et al. 1992). Fraction PB1 is represented by buffer soluble protein whis is rapidly degraded in the rumen (120-400 % h^{-1}). Buffer-insoluble protein minus fraction PB3 is used to estimate fraction PB2. Fraction PB2 is insoluble in buffer but soluble in neutral detergent, while fraction PB3 is insoluble in both buffer and neutral detergent but soluble in acid detergent solution. Fraction PB2 is fermented in the rumen at a lower rate (3-16 % h^{-1}) than the buffer-soluble fraction, and some PB2 fraction escapes to the lower gut. Fraction PB3 is believed to be more slowly degraded in the rumen (0.06-0.55% h^{-1}) than fractions PB1 and PB2 because of its association with the plant cell walls, and a large proportion of PB3 is believed to escape the rumen. Fraction PC is ADICP, which is highly resistant to breakdown by microbial and mammalian enzymes, and it is assumed to be unavailable to the animal.

Carbohydrate was partitioned into: rapidly degradable fraction (CA) which is composed of sugars and organic acids that have a rapid degradation rate of 300% h^{-1}, intermediately degradable fraction (CB1) which is starch and pectin with an intermediate degradation rate of 20-50% h^{-1}, slowly degradable fraction (CB2) which

is available cell wall with a slow degradation rate of 2-10% h^{-1}, and an unfermentable fraction (CC) which is the unavailable cell wall.

v) Energy values

Estimated energy contents for truly digestible crude protein (tdCP), fatty acid (tdFA), neutral detergent fiber (tdNDF) and non-fiber carbohydrates (tdNFC) were calculated separately using the two different approaches as follows:

1) Using NRC 2001-chemical approach (values expressed in %DM):

a. tdNFC (%DM) = 0.98 × (100 - [(NDF - NDICP) + CP + EE + Ash]) × PAF;

where, PAF is the processing adjustment factor and was assumed to be 1.00 according to NRC 2001.

b. tdCP (%DM) = [1 - (0.4 × (ADICP/CP))] × CP

c. tdFA (%DM) = FA, where FA = Cfat -1.

d. tdNDF (%DM) = 0.75 × (NDFn – ADL) × [1 - $(ADL/NDFn)^{0.667}$],

where, NDFn = NDF – NDICP.

2) Using *in situ* assay – biological approach:

a. tdNFC (%DM) = NFC (%DM) × DNFC48 (%),
where, NFC = 100 - ([NDF - NDICP] + CP + EE + Ash) and DNFC48 stands for *in situ* digestibility of NFC after 48 h incubation.

b. tdCP (%DM) = CP (%DM) × DCP48 (%),
where, DCP48 stands for *in situ* digestibility of CP after 48 h incubation.

c. tdFA (%DM) = FA (%DM) × DFA-48 (%),
where, FA = Cfat - 1 and DFA48 stands for *in situ* digestibility of FA after 48 h incubation.

d. tdNDF (%DM) = NDFn (%DM) × DNDFn48 (%),
where, DNDFn48 stands for *in situ* digestibility of NDF after 48 h incubation and corrected for NDICP.

Based on the values of truly digestible nutrients, the energy contents of total digestible nutrient at maintenance (TDN_{1X}), digestible energy at production level of intake (DE_{3x}), metabolizable energy at production level of intake (ME_{3x}) and net energy for lactation at production level of intake (NE_{L3x}) were determined using a summative approach (Weiss et al. 1992) from the NRC 2001 dairy (NRC 2001), while net energy for maintenance (NE_m), and net energy for growth (NE_g) were determined using the NRC 1996 beef (NRC 1996). Both NRC dairy and NRC beef used the same formula to estimate NEg and NEm.

vi) Statistical analysis

(1) Study on the effect of type of DDGS and feedstock grain on chemical profile, protein and carbohydrate fractions and estimated energy values (chemical and biological approaches).

Statistical analyses were performed using the MIXED procedure of SAS (SAS 2005). The model used for the analysis was: $Y_{ij} = \mu + F_i + e_{ij}$, where, Y_{ij} was an observation of the dependent variable ij; μ was the population mean for the variable; F_i was the effect of feed sources, as a fixed effect; batch as replication for the

chemical approach; batch and run as replications for the biological approach; and e_{ij} was the random error associated with the observation ij.

(2) Study on the effect of bio-ethanol plant on chemical profile, protein and lllcarbohydrate fractions and estimated energy values of wheat DDGS.

Statistical analyses were performed using the MIXED procedure of SAS (SAS 2005). The model used for the analysis was: $Y_{ij} = \mu + P_i + e_{ij}$, where, Y_{ij} was an observation of the dependent variable ij ; μ was the population mean for the variable; P_i was the effect of bio-ethanol plant, as a fixed effect; batch as replications; and e_{ij} was the random error associated with the observation ij.

(3) Study on the comparison of NRC 2001-chemical approach with biological approach (*in situ* assay) in the determination of digestible nutrients and energy values of DDGS.

Paired t test procedure of SAS (SAS 2005) and correlation analysis were performed in order to establish the relationship between the NRC 2001-chemical approach and the *in situ* assay-biological approach.

(4) Study on the effect of DDGS type on *in situ* rumen degradability.

Statistical analyses were performed using the MIXED procedure of SAS (SAS 2005). The model used for the analysis was: $Y_{ij} = \mu + F_i + e_{ij}$, where, Y_{ij} was an observation of the dependent variable ijk; μ was the population mean for the variable; F_i was the effect of feed resources, as a fixed effect; batch and run as replications; and e_{ij} was the random error associated with the observation ijk. The relationship between chemical profile and potential degradability was evaluated by correlation analysis.

(5) Studies on effect of bio-ethanol plant on *in situ* degradability of wheat DDGS.

Statistical analyses were performed using the MIXED procedure of SAS (SAS 2005). The model used for the analysis was: $Y_{ijk} = \mu + P_i + e_{ijk}$, where, Y_{ijk} was an observation of the dependent variable ijk; μ was the population mean for the variable; P_i was the effect of plant, as a fixed effect; batch and run as replicates; and e_{ijk} was the random error associated with the observation ijk.

For all statistical analyses, significance was declared at $P<0.05$ and trends at $P\leq0.10$. Treatment means were compared using the Fisher's Protected LSD method.

d) Results

i) Effects of DDGS type (wheat DDGS, corn DDGS vs. blend DDGS) and bio-ethanol plant on sulphur, calcium (Ca), and phosphorus (P)

Dried distillers grains with solubles are low in Ca but high in P and sulfur relative to cattle nutrient needs (NRC 2001). This may have repercussions on animal performance, animal health, and the environment, especially if high levels of DDGS are included in the ration. Sulfur in the ruminant diet is primarily to provide adequate

substrate to ensure maximal microbial protein synthesis. In general, the recommended sulfur content in the diet should be directly related to the protein concentration. However, DDGS contains much higher sulfur due to the addition of sulfuric acid during the ethanol production process. The maximum tolerable level of sulfur in dairy cattle diets is less than 0.4% of dietary DM (NRC 2001). In studies with beef cattle, some strange behaviours and "depressed mood" in cattle fed 60% DDGS were observed (T. McAllister, personal communication). One possibility is that excess sulfur in the diet may be contributing to neurologic changes such as polioencephalomalacia (PEM) ("a disease characterized by a disturbance of the central nervous system. The PEM sometimes occurs on high grain diets, and diets that include plants/grain high on sulfur") (Sheep Industry Development Program 1988). Therefore, the DDGS inclusion level in order to keep sulphur level at a safe concentration should be investigated

The results (Table 1) showed that mineral profiles were significantly different between wheat and corn with wheat higher in Ca, P and sulfur. The mineral profiles were also different among the three types of DDGS with wheat DDGS lower ($P<0.05$) in sulfur (0.39 vs. 0.72 %DM), higher ($P<0.05$) in Ca (0.18 vs. 0.05 %DM) and P (0.91 vs. 0.77 %DM) than corn DDGS, but similar to blend DDGS. There were no significant differences between the two bio-ethanol plants (SK- Plant 1 vs. Plant 2) (Table 1).

ii) Effects of DDGS type (wheat DDGS, corn DDGS and blend DDGS) and bio-ethanol plants on chemical characteristics and profiles

Effects of DDGS type (wheat DDGS, corn DDGS vs. blend DDGS) and bio-ethanol plant on chemical characteristics and profiles are presented in Table 1. Chemical profiles were significantly different among wheat DDGS, corn DDGS and blend DDGS (wheat:corn=70:30). Wheat DDGS was lower ($P<0.05$) in Cfat than corn DDGS (5.0 vs. 16.5 %DM) and blend DDGS (5.0 vs. 8.5 %DM), lower ($P<0.05$) in ADF (11.0 vs. 14.7 %DM) but higher ($P<0.05$) ADL (4.3 vs. 2.8 %DM) than corn DDGS but not significantly different from blend DDGS ($P>0.05$). There was still some residual starch content in all DDGS, which indicated that the completeness of the fermentation was not achieved in any of the DDGS samples. However, residual starch contents in DDGS were not significantly different among wheat DDGS, corn DDGS and blend DDGS and averaged 4.9 %DM. Wheat DDGS was higher ($P<0.05$) in CP than corn DDGS (39.3 vs. 32.0 %DM) and blend DDGS (39.3 vs. 36.8 %DM). There were no significant differences in SCP with average of 13.6 %CP and NPN with average of 100.00 %SCP. Protein solubility could be reduced in DDGS due to the heat applied during processing and/or due to fermentation processing, compared to original grains. It is possible that during fermentation, some soluble proteins were at least partially degraded, leaving a greater proportion of insoluble protein to end up in DDGS. This result is in agreement with previous reports (Firkins et al. 1985; Boila and Ingalls 1994a). Our results showed that SCP in all three types of DDGS was mainly NPN. Wheat DDGS contained similar ($P>0.05$) ADICP to corn DDGS with average of 5.6 %CP but higher ($P<0.05$) than blend DDGS (1.2 %CP). Wheat DDGS also contained higher ($P<0.05$) NDICP than corn DDGS (56.0 vs. 34.4 %CP) but similar ($P>0.05$) to blend DDGS (54.4 %CP). In general, DDGS samples contained

about three times the percentage of most chemical components compared its respective original grain (Spiehs et al. 2002; Nyachoty et al. 2005; Widyaratne and Zijlstra 2006). The amount of CP and Cfat increases while starch decreases as wheat or corn are utilized in DDGS processing (Lee et al. 1991; Widyaratne and Zijlstra 2006). The values shown in the present study are similar to those listed by NRC 2001, with exception of Cfat in corn DDGS (16.5 vs. 10.0 %DM) and CP in wheat DDGS (39.3 vs. 42.3 %DM), and also to those reported by previous studies (Cromwell et al. 1993; Spiehs et al. 2002; Widyaratne and Zijlstra 2006).

There were significant plant effects on chemical characteristics in CFat (6.2 vs. 4.2 %DM), NDF (52.7 vs. 44.9 %DM), NDICP (59.3 vs. 53.8 %CP), and ADICP (0.69 vs. 7.6 %CP) (Table 1). These results indicated that the feedstock used, as well as the different bio-ethanol processing methods used in each plant, such as fermentation, distillation, amount of solubles blended back, and DDGS drying, affected chemical profiles. The amount of solubles added back would affect protein solubility and degradability in the rumen by providing simple sugars that would increase the susceptibility to the Maillard reaction (Belyea et al. 1998). The DDGS from SK-Plant 2 had visually distinguished darker colors due to a higher level of ADICP compared to those from SK-Plant 1.

iii) Effects of DDGS type (wheat DDGS, corn DDGS and blend DDGS) and bio-ethanol plant on protein and carbohydrate sub-fractions

The CP and carbohydrate sub-fractions, partitioned according to the Cornell Net Carbohydrate and Protein System (Sniffen et al. 1992; Chalupa and Sniffen 1994) included PA, PB1, PB2, PB3 and PC for protein fractions, and CA, CB1, CB2 and CC for carbohydrate fractions. Each fraction has different degradation behavior (degradation rate) in the rumen which is highly related to component nutrient availability in ruminants. The effects of DDGS type (wheat DDGS, corn DDGS and blend DDGS) and bio-ethanol plant on protein and carbohydrate sub-fractions are presented in Table 2. Original wheat and corn had significantly different protein sub-fractions but similar carbohydrate fractions (Table 2). Wheat was higher ($P<0.05$) than corn in rapidly degradable non-protein nitrogen (PA: 21.9 vs. 14.5 %CP), higher ($P<0.05$) in rapidly degradable CP fraction (PB1: 2.7 vs. 0.2 %CP), lower ($P<0.05$) in intermediately degradable CP fraction (PB2: 61.9 vs. 80.5 %CP), and higher ($P<0.05$) in slowly degradable CP fraction (PB3: 13.5 vs. 4.7 %CP). There were no significant differences in carbohydrate fractions between wheat and corn with averages of rapidly degradable free sugars (CA: 7.9 %CHO), rapidly degradable CHO fraction (CB1: 74.5 %CHO), intermediately degradable CHO fraction (CB2: 15.5 %CHO) and, unavailable CHO fraction (CC: 2.2 %CHO).

Comparing among the three types of DDGS, wheat DDGS and blend DDGS were higher ($P<0.05$) than corn DDGS in PA (16.3 vs. 14.9 vs. 11.4 %CP) and PB3 (51.2 vs. 53.2 vs. 27.9 %CP). While PB1 was 0 %CP for the three types, corn DDGS was significantly higher than wheat DDGS and blend DDGS in PB2 (54.2 vs. 27.7 vs. 30.8 %CP) and numerically higher in PC (6.4 vs. 4.9 vs. 1.2 %CP). Differences in PB2 and PB3 sub-fractions between wheat DDGS and corn DDGS may be explained by differing protein sub-fraction profile between wheat and corn as well as by differing processing conditions. As a result of heating, the major shifts in the protein

fractions between feedstock grains and DDGS were observed in PB2 and PB3. Approximately half of PB2 in wheat was allocated into PB3 in wheat DDGS, while one third of PB2 in corn was allocated into PB3 in corn DDGS. PC sub-fraction is protein bound to other feed components such as lignin and tannins and is considered not degradable in rumen (Sniffen et al. 1992). As a result of the Maillard reaction, PC sub-fraction was higher in DDGS relative to feedstcok grain. In conclusion, the degradability of protein in rumen decreased in DDGS samples relative to feedstock grains. Although ruminal undegradable protein (RUP) is mainly represented by PB3 and PC sub-fractions, some RUP is present in PB2. Thus, an *in situ* degradability study is required in order to estimate more accurately the quantity of RUP in each type of DDGS.

Although original wheat and corn were not different in carbohydrate fractions, wheat DDGS, corn DDGS and blend DDGS differed significantly (Table 2). Compared to corn DDGS, wheat DDGS was higher ($P<0.05$) in the non-fiber carbohydrate fraction (NFC: 48.3 vs. 18.4 %CHO), higher ($P<0.05$) in highly degradable free sugars fraction (CA: 35.9 vs. 9.1 %CHO), higher in unavailable CHO (CC: 20.4 vs. 14.2 %CHO), similar ($P>0.05$) in rapidly degradable CHO fraction (average 10.8 %CHO), and lower in intermediately degradable CHO (CB2: 31.3 vs. 67.4 %CHO). An explanation for the outstanding difference in the CA fraction between wheat DDGS and corn DDGS may be found in the type of raw starch in the feedstock and processing conditions. CA sub-fraction contains sugars and organic acids (Sniffen et al. 1992). Although the starch content of corn is higher than in wheat, the rate and extent of degradation of wheat starch is higher, suggesting that wheat ethanol is generated more rapidly than corn ethanol. This may imply higher conversion of ethanol to organic acids, such as lactic and acetic acid, when wheat is used as feedstock, and consequently higher CA fraction in wheat DDGS relative to corn DDGS. In addition, wheat DDGS and corn DDGS were manufactured at different bio-ethanol plants, which differed in processing conditions such as amount of yeast utilized and fermentation time.

There were significant bio-ethanol plant effects on protein and carbohydrate sub-fractions between the two plants (Table 2). SK-Plant 1 had lower ($P<0.05$) PB2, PC, and CA, higher ($P<0.05$) PB3, CB2 in DDGS than SK-Plant 2, indicating that bio-ethanol plant processing methods may affect protein and carbohydrate sub-fractions. For example, SK-Plant 1 and SK-Plant 2 used different time and temperature of drying. This higher PC fraction which is not degradable is likely due to more heating applied during processing (Larson et al. 1993).

iv) Effects of DDGS type (wheat DDGS, corn DDGS and blend DDGS) and bio-ethanol plant on energy values as determined from the NRC 2001 formula (chemical approach)

The NRC 2001 formula is the usual method to estimate energy values for feeds. This method is a chemical approach that uses analytical results to estimate the values of truly digestible nutrients. The effects of DDGS type (wheat DDGS, corn DDGS and blend DDGS) and bio-ethanol plant on energy content as determined using the NRC dairy (NRC 2001) and beef (NRC 1996) are presented in Table 3. Wheat and corn had similar ($P>0.05$) tdNFC (average 66.6 %DM) and tdNDF (average 9.0

%DM); however, wheat was higher (P<0.05) in tdCP (14.3 vs. 10.1 %CP) and lower (P<0.05) in tdFA (0.9 vs. 3.4 %DM) than corn. TDN_{1X} was lower (P<0.05) in wheat than in corn (83.4 vs. 88.3 %DM). Wheat was significantly different from corn in energy values of ME_{3X} and NEL_{3X} (Table 3). The estimated energy content for wheat and corn were similar to the tabular values in the NRC 2001, except that TDN_{1X} value, of wheat was lower (83.4 vs. 86.6 %DM).

Wheat DDGS was higher (P<0.05) than corn DDGS in tdNFC (20.1 vs. 8.5 %DM) and tdCP (38.6 vs. 31.2 %DM), but lower (P<0.05) in tdFA (4.0 vs. 15.5 %DM) and tdNDF (11.5 vs. 22.1 %DM). Wheat DDGS had lowest (P<0.05) and corn DDGS had highest (P<0.05) energy values (TDN_{1X}, DE_{3X}, ME_{3X}, NE_{L3X} for dairy; NE_m and NE_g beef cattle) and blend DDGS was in between (Table 3). Our results showed that TDN_{1X} in wheat DDGS was lower (P<0.05) than that in original wheat, but TDN_{1X} in corn DDGS was similar (P>0.05) to original corn grain. This is because corn DDGS significantly reduced tdNFC from 68.2 %DM in original corn to 8.5 %DM, although corn DDGS significantly increased tdFA content from 3.6 %DM in corn to 15.5 %DM (Table 3). However, some studies showed that corn distiller's grains is higher than corn in terms of energy content (Larson et al. 1993; Ham et al. 1994). TDN_{1X} in corn DDGS was higher than the tabular value in NRC (2001) (89.8 vs. 79.5 %DM).

The DE_{3X}, ME_{3X}, NE_{L3X}, NE_m and NE_g values in wheat DDGS were similar (P>0.05) to wheat and corn, suggesting wheat DDGS as an alternative to wheat and corn in dairy and beef diets. However, the DE_{3X}, ME_{3X}, NE_{L3X}, NE_m and NE_g values in corn DDGS were all higher (P<0.05) than in corn, indicating that corn DDGS are superior to original corn in dairy and beef diets. The energy values (DE_{3X}, ME_{3X}, NE_{L3X}, NE_m and NE_g) in the blend DDGS were higher than in wheat, corn and wheat DDGS, suggesting blend DDGS as an alternative to corn and superior to wheat and wheat DDGS in dairy and beef diets. There were no significant effects on TDN_{1X} and energy values (DE_{3X}, ME_{3X}, NE_{L3X}, NE_m and NE_g) between SK-Plant 1 and SK-Plant 2 (Table 3).

v) Effects of DDGS type (wheat DDGS, corn DDGS and blend DDGS) and bio-ethanol plant on energy values as determined from the *in situ* assay (biological approach)

The energy values of a feedstuff are not chemical constituents, thus it is questionable whether these values can be accurately estimated by a chemical assay. The *in situ* assay is a more realistic approach for the estimation of truly digestible nutrients. The effects of DDGS type and bio-ethanol plant on energy content are presented on Table 4. Wheat DDGS was higher (P<0.05) than corn DDGS in tdNFC (23.6 vs. 6.4 %DM) and tdCP (35.5 vs. 22.7 %DM) but lower (P<0.05) in tdFA (3.7 vs. 15.1 %DM) and tdNDF (17.3 vs. 33.9 %DM). Blend DDGS was in between for tdNDF and tdFA but was as high as wheat DDGS for tdNFC and tdCP. As a result, TDN_{1X} and energy values (DE_{3X}, ME_{3X}, NE_{L3X}, NE_m and NE_g) were higher (P<0.05) in corn DDGS relative to wheat DDGS while blend DDGS was in between.

Regarding the plant effect, SK-Plant 1 was lower (P<0.05) in tdNFC (18.5 vs. 27.1 %DM) but higher (P<0.05) in tdFA (5.0 vs. 2.9 %DM) and tdNDF (20.2 vs. 15.3

%DM) than SK-Plant 2; however, there was not significant plant effect in terms of TDN_{1X} and energy values (DE_{3X}, ME_{3X}, NEL_{3X}, NE_m and NE_g).

vi) Comparison of NRC 2001-chemical approach with biological approach (*in situ* assay) in the determination of truly digestible nutrients and energy values of DDGS

Both approaches, chemical and biological, detected that DDGS type and bio-ethanol plant had a significant effect on truly digestible nutrients (tdNDF, tdCP, tdFA and tdNFC), TDN_{1X}, and energy values (DE_{3X}, ME_{3X}, NEL_{3X}, NE_m and NE_g). The difference and the correlation analysis between the chemical and the biological approaches for DDGS samples are presented in Table 5. The numeric difference between the two approaches was significant for the predicted truly digestible nutrients; the highest difference was found in tdNDF (-7.7 %DM) followed by tdCP (4.8 %DM). Higher predicted tdNDF was found when using the *in situ* assay; however, higher tdCP, tdFA and tdNFC were found when using the NRC 2001 approach. Although no significant differences between the two approaches were detected in terms of TDN_{1X} and energy values, the predicted values were slightly higher for the biological approach.

These results are in agreement with a previous study (Yu et al. 2004), in which the highest difference between the chemical and biological approaches was found in tdNDF, being higher when the biological approach was used. NRC 2001-chemical approach estimates tdNDF based on the acid detergent lignin (ADL) content of the feed. Robinson et al. (2004) showed the poor relationship between ADL content and NDF digestibility in different feedstuffs including distillers grains, and concluded that the formula is not an accurate predictor of tdNDF. In that study, metabolizable energy of distillers grains was 13% higher when tdNDF was predicted *in vitro*. Differences among different feeds in the lignin content as well as in the extent to which lignin is bonded to other components of cell wall might be the reason for the deviation in the NDF digestibility (Chesson and Murison 1989). An independent comparison of the chemical and biological approach within each type of DDGS shows that the difference in tdNDF between the two approaches generally increases as the ruminal availability of NDF increases, thus the quantity and digestibility of NDF will determine the accuracy of the NRC 2001-chemical approach when evaluating DDGS products. As NDF availability was lower for wheat DDGS, tdNDF values for wheat DDGS were more accurately predicted by the chemical approach than the other two DDGS types.

In terms of tdCP, the calculation according to NRC 2001 is based on the ADICP content; however, a negative correlation between ADICP and protein digestibility was detected only when ADICP levels were higher than 13% CP (Harty et al. 1998). As shown in Table 3.1, ADICP levels in the current DDGS samples ranged from 1.2 to 6.4%CP. Other studies (Rocha Jr et al. 2001; Detmann et al. 2004; Detmann et al. 2008) have reported that NRC 2001-chemical approach is inaccurate in predicting TDN_{1X} content of feeds under tropical conditions. Of interest for further research would be the use of DDGS samples with higher ADCIP levels to investigate the accuracy of the NRC 2001-chemical approach to predict tdCP. Correlation analysis between the chemical approach and the biological approach for DDGS samples

showed significant and strong relationships for truly digestible nutrients, TDN_{1X}, and energy values.

vii) Effects of DDGS type (wheat DDGS, corn DDGS and blend DDGS) and bio-ethanol plant on *in situ* rumen degradability

The effects of DDGS type and bio-ethanol plant on *in situ* rumen degradability of DM (DDM), OM (DOM), CP (DCP) and NDF (DNDF) after 24 h and 48 h incubations are presented in Table 6. There were significant differences (P>0.05) in DDM and DNDF for 24 h incubation between wheat and corn (DDM24: 90.6 vs. 74.9 %; DNDF: 43.8 vs. 26.9 %), but after a 48 h incubation, the difference disappeared, averaging 91.8% (DDM48) and 48.2% (DNDF48). However, protein degradation patterns were different from DM and NDF. At both incubation times, wheat was always higher than corn (DCP24: 93.5 vs. 53.0 %; DCP48: 95.4 vs. 86.6 %).

Wheat DDGS had significantly higher *in situ* CP degradability (DCP: 61.1 vs. 47.1 % at 24 h; 90.0 vs. 68.1% at 48 h) and lower *in situ* NDF degradability (DNDF: 63.5 vs. 79.4% at 48 h) than corn DDGS, but similar *in situ* degradability to blend DDGS. Comparing the bio-ethanol plants, SK-Plant 1 had lower DDM24 than SK-Plant 2, but similar *in situ* degradability of CP and NDF. In the lactating cow with typical levels of intake, little DM, cell wall, or protein remains at 48 h. There may not be significant quantities at the end of 24 h of fermentation. However, in this study, we would like to know relative differences in maximum rumen degradability between the different types of DDGS. The degradability at the longer incubation can be used as an indicator for total tract digestibility.

viii) Correlation analysis between ADICP and ADL and rumen degradability in overall DDGS, wheat DDGS, corn DDGS and blend DDGS

Acid detergent insoluble crude protein and lignin are known for their adverse effects on digestibility in the animal. In DDGS, the high temperature (100 – 600 °C) applied during the drying process usually results in ADICP formation due to the Maillard reaction (Weiss et al. 1986). While some studies have established a negative correlation between ADICP and CP digestibility in forages (Goering et al. 1972; Yu and Thomas 1976; Van Soest and Mason 1991a; Waters et al. 1992) and non-forages (Arieli et al. 1989; Waters et al. 1992; McKinnon et al. 1995), it is not clear whether ADICP behavior in DDGS is similar to conventional feeds. While Nakamura et al. (1994a) found a moderate correlation between ADICP and protein digestibility, Klopfenstein (1996) did not find any relationship. However, Harty et al. (1998) tested a high number of samples and observed a strong relationship between ADICP and *in vitro* protein utilization when ADICP levels were greater than 13% CP. Although results from the present study (Table 7) indicated a moderate correlation (r = 0.46; P = 0.0327) between ADICP and DM digestibility (24 h incubation) in the overall DDGS samples; no correlation between the ADICP content and the *in situ* digestibility of protein within each type of DDGS was found. Thus, these results would be in accordance with Klopfenstein (1996) and Harty et al. (1998), as ADICP levels in the present DDGS samples were lower than 13 %CP (Table 1). Based on the amount of samples under study, it is concluded that, as long as ADICP levels are

below 13 %CP, ADICP may not be utilized as an accurate indicator of protein utilization in DDGS samples. Unlike the intrinsic ADICP of conventional feeds, the added ADICP in by-products created by the Maillard reaction is 60 - 80% digestible (Waters et al. 1992; Van Soest 1994). This would explain that ADICP levels greater than 13 %CP are required to observe a negative effect on protein digestibility.

The amount of lignin as well as extent to which it is bonded to other components of cell wall affects ruminal digestibility (Chesson and Murison 1989). After 48 h incubation, there was a negative correlation between acid detergent lignin (ADL) and *in situ* degradability of DM, CP, and NDF for wheat DDGS ($r < -0.82$, $P = 0.0035$), but not for corn DDGS and blend DDGS, nor was there correlation after 24 h. Hindrichsen et al. (2006) concluded that ADL is not an accurate method to measure lignin and predict fiber digestibility in concentrates, while Jung et al. (1997) observed that correlation between lignin and the digestibility of DM and NDF was only found for legumes and several types of grasses. Also in the study by Jung et al. (1997), and in accordance with the present study, the higher the lignin content, the stronger negative correlation. Although a limited amount of samples were utilized in the present study, it was concluded that ADL content can only be used as indicator of digestibility for wheat DGGS. The lack of correlation in corn DDGS and blend DDGS may be explained by the lower ADL content relative to wheat DDGS, differences in the distribution of lignin among the three types of DDGS, and weakness of the ADL method.

e) Conclusions and Recommendations

It was concluded that wheat DDGS, corn DDGS and blend DDGS (wheat:corn=70:30) differed in chemical characterization and profiles, mineral concentration (Sulfur, Ca and P), CNCPS protein and carbohydrate sub-fractions, energy values at production levels for both beef and dairy cattle, and *in situ* degradability. The bio-ethanol plant origin also had significant impact on the nutritive value of DDGS. According to NRC 2001-chemical approach, the estimated energy values for wheat DDGS were similar to those for wheat and corn, suggesting wheat DDGS is an alternative to wheat and corn in dairy and beef diets. The estimated energy values for corn DDGS were significantly higher than those for corn, wheat DDGS, and blend DDGS, indicating that corn DDGS is a superior source of energy in dairy and beef diets. These energy values were similar to those obtained by the *in situ* assay-biological approach; however, the prediction of tdNDF and tdCP differed. While a refinement of the NRC 2001 formula to predict tdNDF in DDGS is required, DDGS samples with higher ADICP levels may be required to investigate the accuracy of the tdCP formula.

Results also revealed that the potential degradability of CP and NDF was higher in wheat DDGS and corn DDGS, respectively. While ADICP content was not an accurate indicator of the potential degradability of CP in DDGS samples, ADL seems to be an acceptable indicator of the potential degradability of wheat DDGS. Further research with more samples may help to clarify these relationships. Despite the nutrient variability between plants and the methodology utilized to determine the nutritive value of DDGS, it is clear that wheat DDGS, blend DDGS and corn DDGS are an excellent source of protein and energy for dairy and beef cattle.

Table 1. Comparison of wheat DDGS, corn DDGS and blend DDGS (wheat:corn =70:30) and comparison of different bio-ethanol plants in terms of chemical profile

	Feeds sources						Bio-ethanol plant		
Items	Wheat Grain n = 3	Corn Grain n = 3	Wheat DDGS n = 5	Corn DDGS n = 3	Blend DDGS (W:C=70:30) n = 3	SEM	SK-Plant 1 Wheat DDGS n = 2	SK-Plant 2 Wheat DDGS n = 3	SEM
Basic chemical profile									
DM (%)	89.52 bc	88.77 c	93.76 a	91.44 b	91.61 b	0.697	92.43	94.65	1.050
Ash (%DM)	2.12 c	1.73 c	5.12 a	4.32 b	5.09 a	0.203	4.98	5.21	0.391
OM (%DM)	97.88 a	98.26 a	94.88 c	95.67 b	94.91 c	0.203	95.02	94.79	0.391
Cfat (%DM)	1.91 d	4.59 c	4.98 c	16.53 a	8.53 b	0.432	6.18 a	4.18 b	5.277
Structural carbohydrate profile									
NDF (%DM)	17.22 b	14.47 b	48.07 a	49.46 a	51.50 a	1.701	52.76 a	44.94 b	1.505
ADF (%DM)	3.68 c	3.66 c	10.99 b	14.68 a	10.80 b	0.567	10.82	11.11	0.861
ADL (%DM)	0.99 c	0.54 c	4.32 a	2.80 b	3.66 ab	0.445	3.62	4.78	0.871
Hemicellulose (%DM)	13.55 c	10.82 c	37.04 ab	34.78 b	40.70 a	1.673	41.95 a	33.83 b	0.821
Cellulose (%DM)	2.68 c	3.11 c	6.68 b	11.88 a	7.14 b	0.531	7.20	6.33	0.291
Non-structural carbohydrate profile									
Starch (%DM)	60.35 a	63.41 a	6.32 b	4.38 b	3.99 b	1.417	6.16	6.44	1.520
Crude protein profile									
CP (%DM)	14.28 d	10.13 e	39.32 a	32.01 c	36.82 b	0.832	39.99	38.87	1.664
SCP (%CP)	24.56 a	14.71 b	16.29 b	11.44 c	14.86 b	0.920	16.90	15.88	1.243
NPN (%SCP)	89.62 b	96.70 ab	100 a	100 a	100 a	2.522	100	100	0.000
NDICP (%CP)	13.51 c	4.75 d	56.04 a	34.37 b	54.40 a	1.422	59.33 a	53.84 b	1.028
ADICP (%CP)	0.00 c	0.08 c	4.85 ab	6.44 a	1.17 bc	1.412	0.69 b	7.63 a	0.125
Minerals									
Sulfur (%DM)	0.16 c	0.12 d	0.39 b	0.72 a	0.37 b	0.010	0.37	0.40	0.011
Calcium (%DM)	0.07 b	0.02 c	0.18 a	0.05 bc	0.15 a	0.013	0.19	0.18	0.007
Phosphorus (%DM)	0.37 c	0.29 c	0.91 a	0.77 b	0.92 a	0.037	0.90	0.91	0.072

SEM = standard error of mean. Means with different letters in the same row are significantly different ($P<0.05$)

Table 2. Comparison of wheat DDGS, corn DDGS and blend DDGS (wheat: corn=70:30) and comparison of different bio-ethanol plants in terms of protein and carbohydrate sub-fractions according to CNCPS system

	Feeds sources						Bio-ethanol plant		
Items	Wheat Grain n = 3	Corn Grain n = 3	Wheat DDGS n = 5	Corn DDGS n = 3	Blend DDGS (W:C=70:30) n = 3	SEM	SK-Plant 1 Wheat DDGS n = 2	SK-Plant 2 Wheat DDGS n = 3	SEM
Protein sub-fractions									
PA (%CP)	21.86 a	14.51 b	16.29 b	11.44 c	14.86 b	0.718	16.90	15.88	1.242
PB1 (%CP)	2.70 a	0.20 b	0.00 b	0.00 b	0.00 b	0.569	0.00	0.00	0.000
PB2 (%CP)	61.93 b	80.54 a	27.68 d	54.20 c	30.75 d	1.548	23.77 b	30.28 a	0.754
PB3(%CP)	13.51 c	4.66 d	51.18 a	27.93 b	53.23 a	2.524	58.63 a	46.21 b	1.025
PC (%CP)	0.00 c	0.08 c	4.86 ab	6.44 a	1.17 bc	1.412	0.69 b	7.64 a	0.125
True protein[z] (%CP)	78.14 b	85.41 a	78.85 b	82.12 ab	83.97 a	1.571	82.41 a	76.48 b	1.204
Carbohydrate sub-fractions									
CHO[y] (%DM)	81.69 a	83.54 a	50.58 b	47.14 c	49.57 bc	1.174	48.85	51.74	2.191
NFC[x] (%CHO)	81.29 a	83.22 a	48.34 b	18.36 d	36.49 c	2.841	40.55 b	53.53 a	2.661
CA (%CHO)	7.40 b	8.12 b	35.94 a	9.08 b	28.47 a	3.461	27.96 b	41.27 a	2.291
CB1 (%CHO)	73.89 a	75.10 a	12.40 b	9.28 b	8.02 b	1.918	12.60	12.26	2.470
CB2 (%CHO)	15.79 d	15.22 d	31.26 c	67.42 a	45.77 b	3.552	41.67 a	24.33 b	1.675
CC (%CHO)	2.92 c	1.56 c	20.40 a	14.22 b	17.74 ab	2.003	17.78	22.14	4.037

SEM = standard error of mean. Means with different letters in the same row are significantly different ($P<0.05$).

[z]True protein = PB1 + PB2 + PB3

[y]CHO = total carbohydrates = 100 – CP – Cfat – ash

[x]NFC = non-fiber carbohydrates = 100 – (NDF – NDICP) – Cfat – CP - ash

Table 3. Comparison of wheat DDGS, corn DDGS and blend DDGS (wheat:corn =70:30) and comparison of different bio-ethanol plants in terms of truly digestible nutrients, total digestible nutrient content at maintenance level, and energy values using the NRC 2001-chemical approach

	Feeds sources						Bio-ethanol plant		
Items	Wheat Grain n = 3	Corn Grain n = 3	Wheat DDGS n = 5	Corn DDGS n = 3	Blend DDGS (W:C=70:30) n = 3	SEM	SK-Plant 1 Wheat DDGS n = 2	SK-Plant 2 Wheat DDGS n = 3	SEM
Component digestible nutrient									
tdNFC (%DM)	65.08 a	68.15 a	20.05 b	8.50 d	17.73 c	1.828	19.42 b	27.14 a	1.698
tdCP (%DM)	14.28 c	10.13 d	38.56 a	31.20 b	36.65 a	0.910	39.88	37.68	1.613
tdFA (%DM)	0.91 d	3.59 c	3.98 c	15.53 a	7.53 b	0.432	5.18 a	3.18 b	0.304
tdNDF (%DM)	8.99 c	8.95 c	11.48 c	22.12 a	15.90 b	1.069	14.32 a	9.58 b	0.467
Total digestible nutrient at maintenance level									
TDN_{1X} (%DM)	83.39 b	88.31 a	76.04 d	89.77 a	80.21 c	0.965	78.26	74.56	1.569
Predicted energy values									
DE_{3X} (Mcal kg^{-1} DM) (Dairy)	3.39 c	3.53 bc	3.42 c	3.85 a	3.56 b	0.044	3.52	3.35	0.069
ME_{3X} (Mcal kg^{-1} DM) (Dairy)	2.97 d	3.12 bc	3.01 cd	3.50 a	3.17 b	0.046	3.12	2.94	0.071
NE_{L3X} (Mcal kg^{-1} DM) (Dairy)	1.89 d	2.01 bc	1.94 cd	2.35 a	2.06 b	0.034	2.02	1.88	0.051
NE_m (Mcal kg^{-1} DM) (Beef)	2.06 c	2.16 bc	2.08 c	2.39 a	2.17 b	0.032	2.15	2.03	0.051
NE_g (Mcal kg^{-1} DM) (Beef)	1.40 c	1.48 bc	1.41 c	1.67 a	1.49 b	0.027	1.48	1.37	0.043

SEM = standard error of mean. Means with different letters in the same row are significantly different ($P<0.05$)

Table 4. Comparison of wheat DDGS, corn DDGS and blend DDGS (wheat:corn =70:30) and comparison of different bio-ethanol plants in terms of truly digestible nutrients, total digestible nutrient content at a maintenance level, and energy values at three times maintenance level using the *in situ* assay-biological approach

	Feed sources				Bio-ethanol plant		
Items	Wheat DDGS n = 5	Corn DDGS n =3	Blend DDGS (W:C=70:30) n = 3	SEM	SK-Plant 1 Wheat DDGS n = 2	SK-Plant 2 Wheat DDGS n = 3	SEM
Truly digestible nutrient							
tdNFC (%DM)	23.63 a	6.35 b	16.99 a	2.124	18.49 b	27.06 a	1.782
tdCP (%DM)	35.53 a	22.69 b	33.64 a	1.349	37.37	34.29	2.051
tdFA (%DM)	3.72 c	15.06 a	7.22 b	0.477	4.96 a	2.89 b	0.322
tdNDF (%DM)	17.26 c	33.92 a	22.84 b	1.185	20.15 a	15.34 b	0.736
Total digestible nutrient at a maintenance level							
TDN_{1X} (%DM)	77.77 b	89.85 a	81.73 b	2.068	80.16	76.18	3.505
Predicted energy values							
DE_{3X} (Mcal kg^{-1} DM) (Dairy)	3.47 b	3.79 a	3.59 ab	0.091	3.58	3.40	0.152
ME_{3X} (Mcal kg^{-1} DM) (Dairy)	3.07 b	3.44 a	3.20 ab	0.093	3.18	2.98	0.154
NE_{L3X} (Mcal kg^{-1} DM) (Dairy)	1.98 b	2.30 a	2.09 ab	0.067	2.07	1.91	1.992
NE_m (Mcal kg^{-1} DM) (Beef)	2.11 b	2.34 a	2.20 ab	0.328	2.19	2.06	0.112
NE_g (Mcal kg^{-1} DM) (Beef)	1.44 b	1.63 a	1.51 ab	0.057	1.51	1.39	0.096

SEM = standard error of mean. Means with different letters in the same row are significantly different ($P<0.05$)

In situ assay-biological approach: Truly digestible nutrients (tdNFC, tdCP, tdFA and tdNDF) estimated after 48 h rumen incubation. Energy values (DE_{3X}, ME_{3X}, NE_{L3X}, NE_m, NE_g) calculated according to NRC 2001 formulas.

Table 5. Comparison and correlation analysis between NRC-2001-chemical approach and *in situ* assay-biological approach in the determination of truly digestible nutrients, total digestible nutrient content at maintenance level, and energy values (at three times maintenance level) of DDGS

	Comparison NRC-2001 chemical vs. biological approach					Correlation analysis NRC-2001 chemical vs. biological approach	
Items	$Mean^{chemical}$	$Mean^{biological}$	Numeric difference	SED	P value	r	P value
Truly digestible nutrient							
tdNDF (%DM)	15.59	23.32	- 7.74	0.834	<0.0001	0.98	<0.0001
tdCP (%DM)	36.03	31.24	+ 4.79	0.901	0.0003	0.93	<0.0001
tdFA (%DM)	8.10	7.77	+ 0.33	0.036	<0.0001	1.00	<0.0001
tdNFC (%DM)	18.09	17.11	+ 0.98	0.257	0.0034	1.00	<0.0001
Total digestible nutrient at maintenance level							
TDN_{1X} (% DM)	80.92	82.15	- 1.23	0.689	0.1054	0.93	<0.0001
Energy values for dairy and beef							
DE_{3X} (Mcal/kg DM) (Dairy)	3.58	3.59	- 0.01	0.034	0.6797	0.84	0.0009
ME_{3X} (Mcal/kg DM) (Dairy)	3.18	3.20	- 0.02	0.034	0.6797	0.87	0.0004
NE_{L3X} (Mcal/kg DM) (Dairy)	2.08	2.09	- 0.01	0.024	0.6854	0.91	0.0001
NE_m (Mcal/kg DM) (Beef)	2.19	2.20	- 0.01	0.024	0.6870	0.85	0.0010
NE_g (Mcal/kg DM) (Beef)	1.50	1.51	- 0.01	0.021	0.6919	0.85	0.0010

SED= standard error of the difference. r = Pearson correlation coefficient. Comparison method: Paired t test

Chemical approach: Truly digestible nutrients (tdNFC, tdCP, tdFA and tdNDF) and energy values (DE_{3X}, ME_{3X}, NE_{L3X}, NE_m, NE_g) calculated according to NRC 2001 formulas.

In situ assay-biological approach: Truly digestible nutrients estimated after 48 h rumen incubation. Energy values calculated according to NRC 2001 formulas.

Table 6. Comparison of wheat DDGS, corn DDGS and blend DDGS (wheat: corn =70:30) and comparison of different bio-ethanol plants in terms of *in situ* degradability of dry matter (DDM), organic matter (DOM), crude protein (DCP) and NDF (DNDF) at 24 and 48 h incubations

	Feeds sources						Bio-ethanol plant		
Items	Wheat Grain n = 3	Corn Grain n = 3	Wheat DDGS n = 5	Corn DDGS n = 3	Blend DDGS (W:C=70:30) n = 3	SEM	SK-Plant 1 Wheat DDGS \n = 2	SK-Plant 2 Wheat DDGS n = 3	SEM
In situ degradability of DM at 24 and 48 h incubations									
DDM24 (%)	90.62 a	74.86 b	68.44 c	65.81 c	65.44 c	1.557	64.44 b	71.11 a	1.948
DDM48 (%)	92.29 a	91.35 a	85.40 b	81.80 c	84.47 bc	1.219	85.88	85.09	2.164
In situ degradability of OM at 24 and 48 h incubations									
DOM24 (%)	89.62 a	71.47 b	65.30 c	61.60 c	61.13 c	1.805	60.45 b	68.54 a	2.102
DOM48 (%)	91.55 a	90.23 a	84.12 b	79.75 c	82.69 bc	1.322	84.45	83.90	2.325
In situ degradability of CP at 24 and 48 h incubations									
DCP24 (%)	93.52 a	53.04 cd	61.07 b	47.10 d	56.99 bc	2.747	57.07	63.74	3.289
DCP48 (%)	95.36 a	86.63 b	89.95 ab	68.14 c	87.64 b	2.140	93.04	87.89	3.013
In situ degradability of NDF at 24 and 48 h incubations									
DNDF24 (%)	43.75 ab	26.90 c	42.02 ab	50.49 a	38.68 b	3.416	40.45	43.07	2.968
DNDF48 (%)	51.43 c	44.90 c	63.50 b	79.36 a	63.36 b	2.942	63.60	63.44	3.260

SEM = standard error of mean. Means with the different letters in the same row are significantly different (P<0.05)
Samples were rolled to 0.203 mm prior to rumen incubation and ground to 1 mm for chemical analysis

Table 7. Correlation between ADICP (%CP) and ADL (%DM) and *in situ* digestibility of dry matter (DDM), crude protein (DCP) and neutral detergent fibre (DNDF) at 24 ad 48 h incubations of overall DDGS, wheat DDGS, corn DDGS and blend DDGS (wheat:corn=70:30)

		DDGS type			Bio-ethanol plant	
Items	DDGS Overall n = 11	Wheat DDGS n = 5	Corn DDGS n = 3	Blend DDGS (W:C=70:30) n = 3	SK-Plant 1 Wheat DDGS n = 2	SK-Plant 2 Wheat DDGS n = 3
	----------Pearson Correlation Coefficients: r (P value)----------					
Correlation between ADL and *in situ* degradability						
ADL vs. DDM24	NS	NS	NS	NS	NS	NS
ADL vs. DDM48	NS	r = -0.87 (P = 0.0010)	NS	NS	NS	r = -0.95 (P = 0.0031)
ADL vs. DCP24	NS	NS	NS	NS	NS	NS
ADL vs. DCP48	NS	r =-0.89 (P = 0.0006)	NS	NS	NS	r = -0.88 (P = 0.0204)
ADL vs. DNDF24	r = -0.48 (P = 0.0224)	NS	NS	NS	NS	NS
ADL vs. DNDF48	r = -0.72 (P = 0.0002)	r = -0.82 (P = 0.0035)	NS	NS	NS	r = -0.98 (P = 0.0007)
Correlation between ADICP and *in situ* degradability						
ADICP vs. DDM24	r = 0.46 (P = 0.0327)	NS	NS	NS	NS	NS
ADICP vs. DDM48	NS	NS	NS	NS	NS	NS
ADICP vs. DCP24	NS	NS	NS	NS	NS	NS
ADICP vs. DCP48	NS	NS	NS	NS	NS	NS
ADICP vs. DNDF24	NS	NS	NS	NS	NS	NS
ADICP vs. DNDF48	NS	NS	NS	NS	NS	NS

r = Pearson correlation coefficient

f) Acknowledgements

Purina Land O' Lakes awarded with travel expenses to attend and present at the 2008 Distillers Grains Symposium

g) Other

i) Scientific publications

W.G. Nuez Ortín, P. Yu*. 2009. Nutrient Variation and Availability of Wheat DDGS, Corn DDGS and Blend DDGS from BioEthanol Plants. **Journal of the Science of Food and Agriculture. 89: 1754–1761.**

W.G. Nuez-Ortín, P. Yu*. 2010. Estimation of Ruminal and Intestinal Digestion Profiles, Hourly Degradation Ratio and Potential N to Energy Synchronization of Co-Products of Bioethanol Production. **Journal of the Science of Food and Agriculture. In Press.**

ii) Conference presentations

- 2008 Distillers Grains Symposium, Kansa City (MO), USA. Presented in May 2008. (Poster presentation)
- 2009 Joint Meeting of ASDA, CSAS, ASAS, Montreal (QC), Canada. July 2009. Four abstracts submitted (One oral presentation and three poster presentations).
- 2009 European Society of Animal Production, Barcelona, Spain. August 2009. One abstract submitted (Oral presentation).

2) Characterization of nutritional quality and economic value of DDGS – Protein Functionality

b) Introduction

During ethanol production, DDGS undergoes various heat treatments during the liquefaction, distillation and drum drying stages. These steps each have the potential to denature protein adversely affect the functional properties of the protein. The objective of this project is to assess the impact of high temperature processing on protein functionality for wheat proteins in the DDGS. Characterization of the functional properties may provide insight to other potential feed usage of DDGS by-products from the ethanol industry. This project focused on developing protocols for extracting gluten protein from unprocessed wheat grain, wet distillers' grain, thin stillage, condensed thin stillage (syrup) and DDGS by changing solvent conditions. Once the protein extraction methods have been validated, standard protein functionality testing will be carried out on the protein-rich samples.

c) Methods

Wheat grain and co-products were sampled during ethanol production (05/30/07) at Husky Energy (Lloydminster, SK). Samples consisted of a 75% CPS (Canadian Prairie Spring): 25% HRS (Hard Red Spring) wheat blend, and included wheat flour, condensed syrup (CS) and DDGS. In the present study, only one processing-batch was tested due to changes in feedstock from 100% wheat to a corn/wheat blend. This

change significantly influenced the available material to analyze. All samples were ground into a fine powder using a coffee grinder.

i) Proximate Analysis

Chemical analyses on the wheat flour, CS and the DDGS were performed according to Association of Official Analytical Chemists (AOAC, 2000) Methods 925.10, 923.03, 920.85 and 979.09 for moisture, ash, lipid and crude protein, respectively. Carbohydrate content was determined based on percent differential from 100% (Table 1).

Table 1. Compositional analysis of wheat-based co-products arising from ethanol fuel production (standard deviation are in brackets, n=2, wet basis).

Powder	Moisture	Ash	Crude Protein	Lipid	Carbohydrate
Wheat flour	12.35 (0.01)	1.59 (0.00)	10.97 (0.03)	1.68 (0.18)	73.41
CS	71.14 (0.04)	2.19 (0.02)	11.45 (0.04)	1.67 (0.06)	13.55
DDGS	10.54 (0.10)	4.74 (0.00)	33.43 (0.05)	3.32 (0.25)	47.97

ii) Protein separation

Initially, 5g of wheat flour, CS and DDGS was extracted in 50mL of 0.05M HCl solution (pH 2.8) with 1% (v/v) 2-mercaptoethanol for 1h under constant stirring at room temperature, according to modified methods of Falcao-Rodrigues et al. (2005). The mixture was then centrifuged for 10 min at 15,300 x g for 10 min using a Beckman J2-HC Centrifuge (Beckmann Instruments Inc., Palo Alto, CA). The supernatant was decanted for further separation, leaving a pellet containing in-soluble wheat protein. The pH of the pellet was neutralized with NaOH, washed with distilled de-ionized water, and then centrifuged at 15,300 x g for 10 min. The washing procedure was performed 3 times, followed by freeze-drying, to give an in-soluble protein fraction. The supernatant was then neutralized with NaOH, followed by the addition of 70% (v/v) ethanol to help precipitate the glutenin-rich soluble fraction. The mixture was stirred overnight, and then centrifuged at 15,300 x g for 10 min. The pellet was washed 3 times (as described previously) and then freeze dried to give the acid-soluble protein fraction. The subsequent supernatant was also freeze dried to yield a gliadin-rich alcohol-soluble fraction.

iii) Water (WHC) and fat holding (FHC) capacity

WHC and FHC for wheat flour, CS and DDGS were determined based on modified methods of Admedna et al. (1999) and Koivurinta et al. (1980). A 0.5g sample was weighed into a 50 mL pre-weighed centrifuge tube. For each sample, 5 mL of buffer solution (100 mM sodium phosphate buffer) was added in small increments under constant stirring using a glass rod, to ensure the sample was thoroughly mixed. Samples were vortexed at low speed for 10 s every 5 min for 30 min, before being centrifuged at 2,790 x g for 10 min (Beckman J2-HC Centrifuge, Beckmann Instruments Inc., Palo Alto, CA). The supernatant was decanted, and the tube with the sediment was weighed. WHC (g of water/g of sample) was calculated from the ratio of (W2-W1)/Wo, where Wo is the weight of the dry sample (g), W1 is the weight of the tube plus the dry sample (g), and W2 is the weight of the tube plus

the sediment (g). WHC was tested as a function of pH (3-8) for each sample. In the case of FHC, 5 mL of canola oil was used instead of the buffer solution. All samples were done in duplicate. The FHC was determined using a similar equation as WHC, except the weight of oil was used.

d) Results

i) Protein extraction

This study sought to develop a separation protocol that could extract both soluble- and insoluble protein-rich fractions from wheat flour and co-products of the ethanol fuel industry. It was thought that proteins would undergo substantial thermal denaturation throughout the process, leading to significantly reduced solubility of the native protein. Wheat is high in prolamin-type proteins, such as gluteninin (soluble in dilute acid) and gliadin (soluble in alcohol) (together known as gluten), along with other minor albumin and globulin proteins. After extraction, crude protein levels in wheat flour were primarily in a soluble-form, whereas proteins in both co-products were mainly in an in-soluble form (Table 2). Based on the protein levels found within each fraction, only the water- and fat-holding capacities for the in-soluble protein fractions of CS and DDGS were tested, and contrasted against wheat flour as the control.

Table 2. The percentage of crude protein (dry basis) found within each extracted fraction from wheat flour, CS and DDGS (standard deviation is in brackets, n=2)

	Percentage of crude protein within each fraction		
Sample	Wheat flour	CS	DDGS
In-soluble protein fraction	9.00 (0.34)	65.31 (0.01)	42.15 (0.60)
Acid-soluble fraction	31.39 (1.11)	18.04 (1.18)	19.64 (0.52)
Alcohol-soluble fraction	48.14 (2.50)	13.75 (0.38)	13.79 (0.89)

ii) Water- and fat-holding capacity

WHC was found to decline slightly within increasing pH between 3 and 8 for all wheat flour and co-product samples, however the magnitude was approximately 2.5-3 times lower for wheat flour then the co-product fractions. In addition, the WHC for the DDGS fraction was slightly higher than the CS sample over the majority of the pH range. It was hypothesized that the heat-treated co-products are more reactive, as the protein structure is more unraveled than the untreated form (i.e., wheat flour). A similar trend is seen in the FHC data.

e) Conclusions and Recommendations

It was concluded that wheat flour was found to be higher in soluble proteins, whereas both co-product fractions consisted primarily of in-soluble proteins. The ability to bind both water (water-holding capacity) and fat (fat-holding capacity) was ~2-3 times greater for both co-product fractions relative to the wheat flour, suggesting that proteins emerging from the ethanol process may be more unraveled (denatured), and have a greater amount of reactive groups exposed. This preliminary study successfully laid the foundation for a recently funded ADF project (#2007-0217) investigating the functional and nutritional consequences of protein co-products from high temperature ethanol processing.

3) Supplementation of Beef Cow Diets with DDGS

b) Introduction

The specific objectives of this project are:

i) To evaluate the effects of DDGS supplementation to pregnant beef cows consuming stockpiled forages allocated to supply maintenance levels of energy and protein on intake, performance (body weight change and body condition change) and reproductive efficiency.

ii) To evaluate the effects of DDGS supplementation to pregnant beef cows consuming straw-chaff + hay allocated to supply maintenance levels of energy and protein on intake, performance (body weight change and body condition change).

iii) To evaluate the economics ($/cow/day) of feed management systems.

Effect of supplementing beef cows grazing forages with wheat-based dried distillers' grains with solubles on animal performance and intake

c) Methods

i) Study site

A two year grazing trial was conducted on stockpiled crested wheatgrass (*Agropyron cristatum* L.) pastures at the Western Beef Development Centre's Termuende Research Ranch near Lanigan, Saskatchewan, Canada (51°51 'N, 105°02 'W). Stockpiling of perennial forage was initiated on 15 July in 2007 and 2008. Chemical composition of stockpiled pasture forage is presented in Table 1. Six pastures with gently rolling topography were subdivided using high tensile electric fencing into four 1.8 ha paddocks for the grazing study. Soils at the study site were a mixture of Oxbow Orthic Black and carbonated Oxbow with a loam texture.

ii) Grazing animal management

Forty-eight dry, pregnant (83±22 d) multiparous Black Angus cows (BW±SD; 609±11 kg) grazed stockpiled crested wheatgrass pastures for 34 days (3 October to 6 November) in 2007 and 42 days (19 September to 31 October) in 2008. Cows were stratified by BW and days pregnant to maintain homogeneity between groups and assigned randomly to 1 of 3 replicated (n=2) supplementation strategies: (1) wheat-based dried distillers' grains with solubles (DDGS); (2) commercial range pellet (COMM); or (3) control (no supplement; CONT). The DDGS was a 70% wheat, 30% corn blend obtained from Husky Energy (Lloydminster, Saskatchewan, Canada). The commercial range pellet was custom formulated by FeedRite Ltd. (Humboldt, Saskatchewan, Canada) to be nutritionally similar to the DDGS supplement (Table 1). Groups were moved to the next paddock when crested wheatgrass residue reached an approximate height of 4 cm.

Table 1 Chemical composition of pasture forage and supplements

Nutrient	Pasture[z]	DDGS[y]	Commercial Pellet[x]
DM (%)	87.5	90.0	91.0
CP (% DM)	7.3	38.5	38.6
NDF (% DM)	74.6	50.8	34.5
ADF (% DM)	46.9	19.8	16.0
ADL (% DM)	11.5	-	-
Phosphorus (% DM)	-	0.8	0.8
Sulfur (% DM)	-	0.8	0.9
NDIN (% N)	-	4.1	1.8
ADIN (% N)	14.2	-	-
IVDMD (% DM)	56.4	88.8	90.8
IVOMD (% DM)	55.6	91.7	93.9
TDN[w] (% DM)	49.0	80.0	84.3
DE[w] (Mcal kg^{-1} DM)	2.1	3.3	3.4

[z]Stockpiled crested wheatgrass pasture

[y]DDGS = wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend)

[x]Ingredient composition presented in Appendix Table A.1

[w]Calculated using the Penn State Equations based on ADF content (Adams 1995)

Cows receiving supplement were fed the equivalent of 1.2 kg per head per day (9.6% of total dry matter intake) (Table 2) or 0.2% of BW daily, fed three times per week between 0800 and 0900. Cows had *ad libitum* access to 2:1 mineral supplement (20.0% Ca, 10.0% P, 60 ppm Se, 70 ppm Co, 200 ppm I, 3000 ppm Cu, 9000 ppm Mn, 10 000 ppm Zn, 3700 ppm Fe, 1000 ppm F (max), 1 000 000 IU/kg Vitamin A (min), 150 000 IU/kg Vitamin D (min), 1000 IU/kg Vitamin E (min); FeedRite Ltd., Humboldt, Saskatchewan, Canada) and cobalt-iodized salt (99.0% NaCl (min), 39.0% Na, 150 ppm I, 100 ppm Co; FeedRite Ltd., Humboldt, Saskatchewan, Canada) over the course of the trial. Water was supplied to each paddock in troughs fed via underground pipe system. Parameters measured to evaluate cow performance included BW, BCS, and subcutaneous body fat thickness. Body weights were taken over 2 consecutive days at the start and end of trial and every 14 d throughout the course of the trial. Cow BW was corrected for conceptus gain using the equation from NRC (1996):

$$\textit{Conceptus weight (kg)} = \textit{(calf birth weight x 0.01828)} \times e^{[(0.02xt) - (0.0000143xtxt)]}$$

Body condition score was determined by the same experienced technician at the beginning and end of the trial using the Scottish scale where 1=emaciated and 5=grossly fat (Lowman et al. 1976; Wildman et al. 1982). Ultrasound measurements of subcutaneous body fat thickness were determined between the 12th and 13th rib and at the thurl location using an Aloka SSD-500V ultrasound machine and Aloka UST-5044 probe (3.5 MHz). Guidelines for animal care (Canadian Council on Animal Care 1993) were followed at all times for all animals used in this experiment.

Table 1 Feed ingredients and nutrition composition of ration[z]

	Treatments[y]		
	DDGS	COMM	CONT
Predicted intake (kg DM/hd/d)	13.0	12.9	12.8
Feed	% of ration		
Pasture[x]	89.5	89.8	99.3
DDGS	9.7	-	-
Commercial Supp	-	9.5	-
2:1 Mineral	0.5	0.4	0.4
Salt	0.4	0.4	0.4
Chemical composition[w]			
CP (% DM)	10.3	10.2	7.3
NDF (% DM)	71.7	70.2	74.0
TDN (% DM)	51.7	52.0	48.7
DE (Mcal kg^{-1} DM)	2.2	2.2	2.1

[z]Rations formulated using CowBytes Beef Ration Balancer Program. Version 4. (Alberta Agriculture Food and Rural Development 1999)

[y]DDGS = cows supplemented with wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend); COMM = cows supplemented with commercial range pellet; CONT = cows received no supplement

[x]Stockpiled crested wheatgrass pasture

[w]Calculated from average nutrient composition of ingredients.

iii) Estimation of forage utilization

Ten randomly distributed plots (0.25 m^2) were clipped to a 3 cm stubble height as cows entered and exited each paddock to estimate available and residual forage, respectively. Previously clipped areas were not re-harvested. The difference between the weight of the available and residual forage samples after drying at 55°C for 72 hours was used to estimate forage utilization by the cows as per the Herbage Disappearance (Weight Estimate) Method (Jasmer and Holechek 1984):

$$Pasture\ \ utilizatio\ n\ (\%) = \frac{\left(g\ DM\ \ per\ 0.25\ m^2\ available\ - g\ DM\ \ per\ 0.25\ m^2 residual \right)}{g\ DM\ \ per\ 0.25\ m^2 available}$$

Grams per 0.25 m^2 were extrapolated to determine kg per ha and forage intake was estimated using the following equation:

$$DMI\ \ (kg) = \frac{\left(kg\ DM\ \ p^{-1} allocated\ - kg\ DM\ \ p^{-1} residual \right)}{n^{-1} / p}$$

where p = the number of days the paddock was grazed and n = the number of cows per experimental unit.

iv) Laboratory analysis

Forage DM was determined by drying clipped samples at 55°C for 72 h in a forced air oven. Prior to chemical analysis, forage samples were ground through a 1-mm screen (Thomas-Wiley Laboratory Mill Model 4; Thomas Scientific, Swedesboro, NJ, USA). Representative supplement samples were also ground to pass through a 1-mm screen using a Retsch ZM-1 grinder (Haan, Germany). All feed samples were analyzed for moisture, CP, acid detergent fibre (ADF), neutral detergent fibre (NDF), in-vitro dry matter digestibility (IVDMD), and in-vitro organic matter digestibility (IVOMD) and forages were analyzed for acid detergent lignin (ADL) and acid detergent insoluble nitrogen (ADIN). Additionally, supplements were analyzed for phosphorus, sulfur, and neutral detergent insoluble nitrogen (NDIN). Total digestible nutrients (TDN; % DM) and digestible energy (DE; Mcal kg^{-1} DM) were calculated for forage samples using the grass-legume Penn State equation based on ADF and for supplement samples using the cereal grains Penn State equation (Adams 1995). Moisture was determined according to the procedure outlined by the Association of Official Analytical Chemists (method #930.15; AOAC 2000). Crude protein (N x 6.25), NDIN, and ADIN concentrations were determined using the Kjeldahl procedure (method #984.13; AOAC 2000) using the 2400 Kjeltec Analyzer Unit (FOSS Tecator, Hoganas, Sweden). NDF and ADF were analyzed using an ANKOM 200 Fiber Analyzer (ANKOM Technology, Fairport, NY). NDF was analyzed without sodium sulfite in order to further determine NDIN content of the samples (Hertz and Mertens 1996). Lignin content was evaluated using the beaker method outlined by ANKOM Technology.

In vitro dry matter digestibility and IVOMD were estimated using the filter bag technique (Daisy[II], ANKOM Technology Corporation, Fairport, NY). Artificial saliva was inoculated with rumen fluid strained through four layers of cheese cloth. Rumen fluid was collected from a ruminally-fistulated Holstein cow fed 70% silage and 30% concentrate (custom pellet; DM basis). Phosphorus and sulfur were analyzed according to the procedures outlined by Qian et al. (1994) and Kowalenko (1993), respectively.

v) Data analysis

The Proc Mixed Model procedure of SAS (2005) was used for all statistical analysis except body condition score. Differences were considered significant when $P < 0.05$; means were separated using Tukey's multi-treatment comparison method (Saxton 1998). Cow BW, rib and rump fat, forage utilization, and dry matter intake estimations were analyzed as fixed effects in a randomized complete block design with year considered as a random effect. The experimental model was:

$$Y_{ij} = \mu + \rho_i + \alpha_j + e_{ij}$$

where μ is the overall mean, ρ_i is the block or random effect to the *i*th year, α_j is the fixed effect of the *j*th treatment, and e_{ij} is the error term specific to the experimental unit (cow group) assigned to the *j*th treatment within the *i*th year.

Because cow body condition score data are discrete values with no unit, cow body condition score data was analyzed using the Proc Glimmix procedure of SAS (2005). Proc Glimmix is used to fit statistical models to data with correlations or non-constant

variability and where the response is not necessarily normally distributed (SAS Institute Inc. 2005).

d) Results

i) Pasture quality

Chemical composition of stockpiled crested wheatgrass pasture forage and supplements are presented in Table 1. Average forage quality of the pasture was higher than anticipated. Total digestible nutritents, calculated using the Penn State equations based on ADF content (Appendix Equation A.1; Adams 1995), was 49.0% and IVDMD was 56.4%. As such, pasture forage could provide adequate energy for the grazing beef cows (NRC 1996). Average CP was 7.3%, which is greater than the 6-7% CP recommended for beef cows (NRC 1996; Mathis et al. 2000). However, during the study, CP content decreased 1.9% (Figure 1), indicating the potential for CP to be deficient.

Forage quality spiked in the third graze period. Precipitation in the second week of October in both years may have caused a flush of regrowth, increasing forage quality and availability in the third graze period. However, over the course of the trial, forage quality declined. Crude protein decreased from 7.6% to 5.7% while NDF increased from 73.2% to 77.5% and ADF levels increased from 45.3% to 50.1% (Figure 1). It is well documented that forage digestibility decreases as plants mature, weather, and senesce due to decreased photosynthetic leaf material and increased structural stem components, including cellulose, hemicellulose, and lignin (Wilson 1982; Jones and Wilson 1987; Huston and Pinchak 1991; Van Soest 1994; Vallentine 2001). Reduced dietary intake in response to seasonal advancement has been observed in other studies (McCollum and Galyean 1985a; McCollum et al. 1985; Johnson et al. 1998). Beck et al. (2006) found the extent of *in situ* organic matter (OM) disappearance in the rumen decreased as the ADF content in stockpiled forage increased. Cline et al. (2009) found that total tract and apparent ruminal organic matter digestibility decreased as the grazing season progressed, as did organic matter intake. In the current study, IVOMD was estimated to decline 10.2% in the pasture forage during the trial (Figure 2). This decline in IVOMD is similar to that reported by Baron et al. (2004) for crested wheatgrass pasture.

ii) Forage utilization

Available and residual forage levels were not different ($P = 0.43$ and 0.89, respectively) between treatments (Table 3). However, during the trial, available forage was significantly greater ($P = 0.02$) during the third graze period, which occurred during mid-October for both years of the study. Baron et al. (2004) also found DM yield of crested wheatgrass pasture (*Agropyron cristatum* L.) was greatest at the mid-October time period. In this study, a high standard error of the mean (SEM; Table 3) may be reflective of the low number of quadrat samples taken and the variability associated with the estimation technique.

Estimated forage utilization did not differ ($P = 0.79$) between treatment groups. This agrees with results reported by Poore et al. (2006), who observed no difference ($P > 0.20$) in forage use as affected by whole cottonseed meal plus corn grain supplementation on stockpiled fescue pasture. However, in the current study, cows

receiving supplement numerically utilized 6% more forage than the unsupplemented control cows (Table 3), while heifers in the study by Poore et al. (2006) utilized 3.4% less forage when supplemented. Forage utilization was not different ($P > 0.05$) during the course of the study.

Forage utilization data was used to estimate forage intake on a per head per day basis (Table 4). Dry matter intake of pasture forage was not affected ($P = 0.37$) by supplementation strategy. This is in contrast with other studies (Chase and Hibberd 1987; Koster et al. 1996; DelCurto et al. 1999; Mathis et al. 1999; Bandyk et al. 2001) which have reported increased forage intake as a result of protein supplementation and may have been a result of low experimental power. In an extensive review, Moore et al. (1999) reported that forage intake was often increased with supplementation if forage intake alone was less than 1.75% of BW and the forage TDN to CP ration was less than 7. In the current trial, the forage intake of control cows was 1.48% of BW. Based on this data, forage intake was expected to increase with protein supplementation. However, it is known that supplementation effects are influenced by forage quality and supplement composition (Huston et al. 1993). Average TDN:CP ratio of the pasture forage was 6.7, however due to selective grazing, it is likely that the forage consumed by the cows had a higher TDN:CP ratio (Vallentine 2001). Furthermore, Kartchner (1980) found no effect of protein supplementation when forage DM digestibility (DMD) was 55 percent. Average IVDMD of stockpiled crested wheatgrass pasture in this study was 56.4 percent (Table 1).

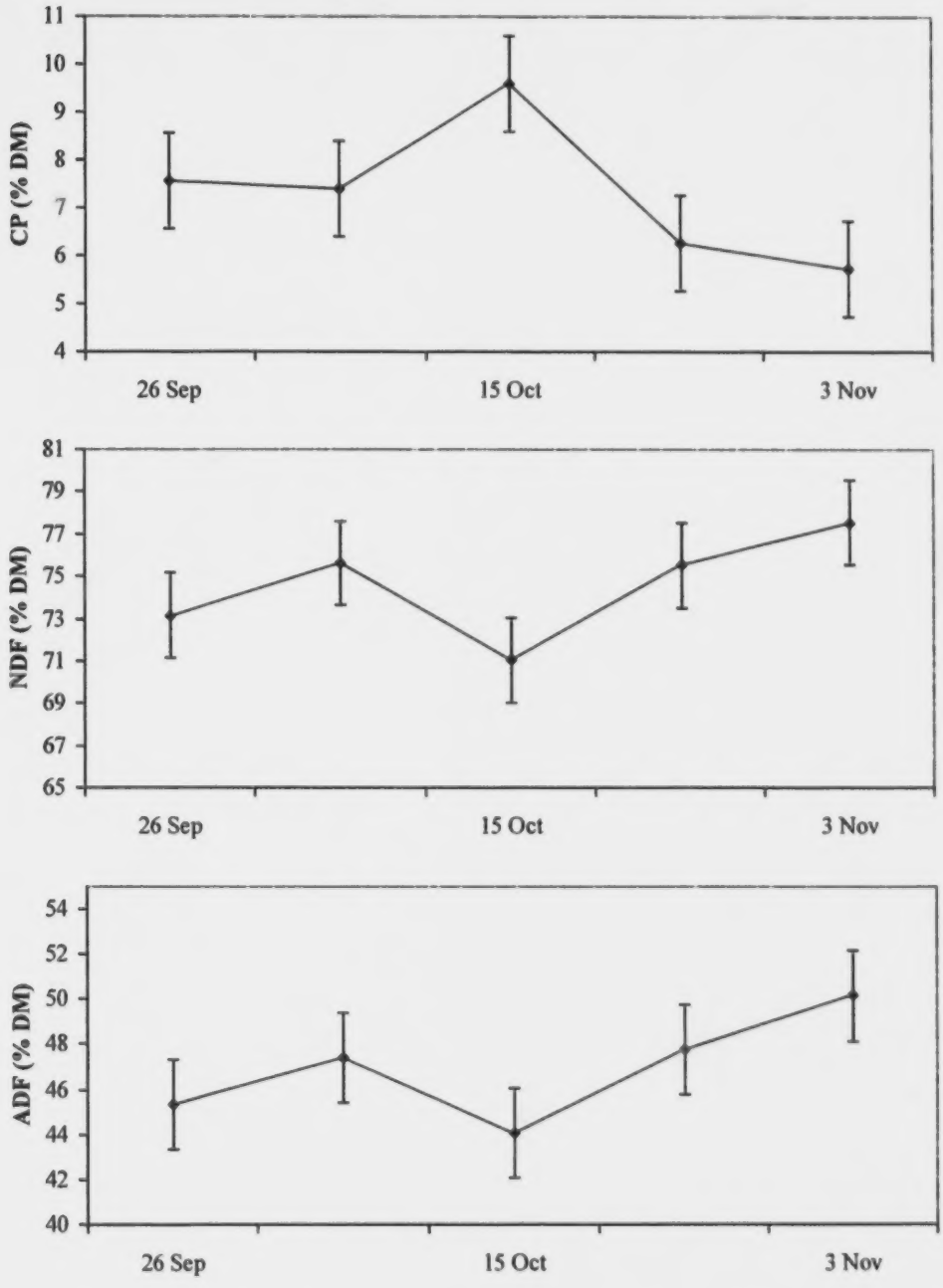

Figure 1. Forage quality of stockpiled crested wheatgrass pasture (CP = crude protein; NDF = neutral detergent fibre; ADF = acid detergent fibre)

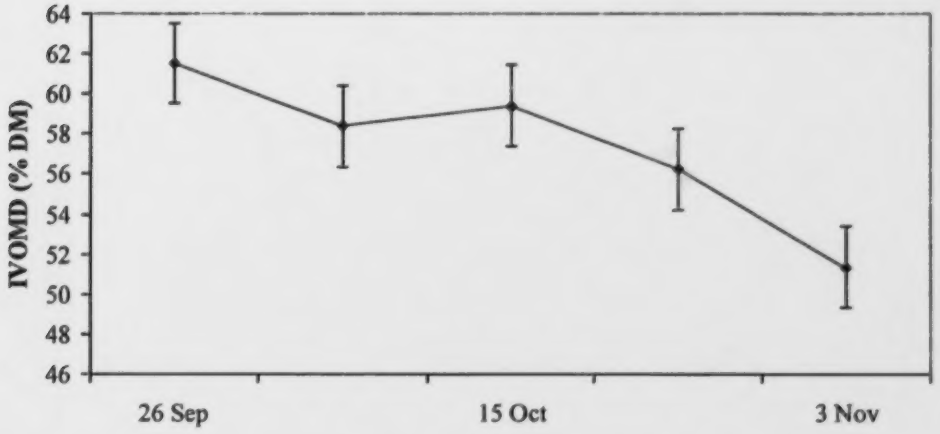

Figure 2. *In vitro* organic matter digestibility (IVOMD) of stockpiled crested wheatgrass pasture

Table 2 Effects of supplementation on pasture utilization

	Treatment[z]				Graze Period					P values[x]		
	DDGS	COMM	CONT	SEM[y]	1	2	3	4	SEM	trt	gp	trt*gp
Available forage (kg ha^{-1})	1943.8	2042.4	1769.9	571.54	1730.7b	1830.4b	2407.6a	1706.2b	577.91	0.43	0.02	0.7
Residual forage (kg ha^{-1})	1073.4	1120.3	1110.7	482.19	1126.5	1102.6	1060.4	1116.3	483.93	0.89	0.94	0.83
Percent utilization	39.9	40	34.3	0.09	31.1	41.8	49.3	30.1	0.1	0.79	0.25	0.58

[z]DDGS = cows supplemented with wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend); COMM = cows supplemented with commercial range pellet; CONT = cows received no supplement

[y]Means separated using Tukey's multi-treatment comparison method. SEM = standard error of mean

[x]trt = treatment effects; gp = graze period effects; trt*gp = treatment by graze period interaction

Table 3 Estimated DM intake of dry, pregnant beef cows grazing stockpiled crested wheatgrass pasture

	Treatment[z]				Graze period[y]					P value[x]		
Item	DDGS	COMM	CONT	SEM	1	2	3	4	SEM	trt	gp	trt*gp
Dry matter intake, kg d^{-1}												
Supplement	1.2	1.2	0.0	N/A	0.7	0.7	0.8	0.8	N/A	N/A	N/A	N/A
Pasture	11.7	12.6	9.1	1.81	6.3b	10.3b	18.3a	9.7b	2.09	0.37	<0.01	0.66
Total	12.9	13.8	9.1	1.81	7.0b	11.1b	19.2a	10.5b	2.09	0.16	<0.01	0.66
Dry matter intake, % BW												
Supplement	0.19	0.19	0.00	N/A	0.12	0.12	0.13	0.3	N/A	N/A	N/A	N/A
Pasture	1.86	2.01	1.47	0.291	1.02b	1.67ab	2.86a	1.57b	0.335	0.40	<0.01	0.67
Total	2.05	2.21	1.47	0.290	1.15b	1.79ab	2.99a	1.71b	0.335	0.18	<0.01	0.68

[z]DDGS = cows supplemented with wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend); COMM = cows supplemented with commercial range pellet; CONT = cows received no supplement

[y]Graze period: period 1 = 11 d; period 2 = 10 d; period 3 = 10 d; period 4 = 7 d

[x]trt = treatment effects; gp = graze period effects; trt*gp = treatment by graze period interaction

[a-b]Means with different letters in the same row are significantly different ($P < 0.05$) using Tukey's multi-treatment comparison method.

SEM = standard error of mean

Unsupplemented or control cows were estimated to consume 9.1 kg of pasture per day. This is similar to the estimated forage intake of 9.98 kg per day for a 620 kg cow based on the observations of Mertens (1987; 1994) and Ferrell et al. (1999), where predicted dry matter intake of long stem forage is 1.2% of BW as NDF. Supplemented cows did not ($P = 0.37$) consume more pasture forage than the control cows. This contrasts with the results of Morris et al. (2005), who found supplementation of graded levels of corn-based DDGS linearly decreased DMI of both high (65% TDN) and low (53% TDN) quality forages. Similar results were observed by MacDonald et al. (2007) when corn-based DDGS was supplemented at different levels to beef heifers grazing smooth bromegrass pastures with average TDN values of 58.2 percent. The energy level of the pasture forage in the current study was lower (49.0% TDN; Table 1) than the forages in these studies, perhaps eliminating the substitution effects observed by Morris et al. (2005) and MacDonald et al. (2007).

iii) Cow performance

Supplementing cows with either DDGS or commercial range pellet had no effect ($P > 0.05$) on cow BW, body fat, or body condition (Tables 5 and 6). These results do not agree with other studies that reported significant effects on BW and condition with protein supplementation (Clanton and Zimmerman 1970; Huston et al. 1999; Bohnert et al. 2002a). Cows supplemented with DDGS or COMM gained 10.0 and 6.8 kg respectively, while cows receiving no supplement gained only 1.8 kg BW. Rib and rump fat depth of supplemented cows increased 1.1 and 1.5 mm for DDGS and COMM treatments, respectively, while unsupplemented cows lost 0.8 mm.

Effect of supplementation on body condition score (BCS) is presented in Table 6. The majority of the cows (72.4% supplemented, 86.7% unsupplemented) maintained (0 score change) or gained 0.5 BCS. During the trial, 24.1% of cows supplemented with DDGS gained one BCS compared to only 6.7% of the unsupplemented (control) cows. For cows supplemented with a commercial range pellet, 17.2% gained one BCS. Very few animals (3.4% supplemented, 6.7% unsupplemented) lost (negative change) body condition.

Because the energy levels of the pasture forage met maintenance requirements of gestating beef cows, DDGS and commercial range pellet served as protein supplements. There have been variable results reported on the effects of protein supplementation on beef cow performance. Bohnert et al. (2002a) reported positive cow BW and body condition score changes when soybean meal-based protein supplements were fed to pregnant beef cows consuming low quality meadow hay (5.2% CP; 60.1% NDF). Similarly, Huston et al. (1999) found feeding cottonseed meal to beef cows grazing native range in western Texas reduced losses in BW and BCS. Clanton and Zimmerman (1970) also reported increased cow BW and body condition when soybean meal was supplemented to cows consuming bromegrass hay (8.1% CP). Conversely, Smith et al. (2001) found beef cows grazing native winter range in eastern Colorado lost BW and condition ($P < 0.05$) when supplemented with corn-based DDG. These authors concluded that degradable intake protein requirements were not met by the high RUP value of the DDG.

Table 4 Effect of supplementation on performance of beef cows grazing stockpiled pasture

	Treatment[z]				
	DDGS	COMM	CONT	SEM[y]	P value
Body weight[x], kg					
Initial	608.1	607.3	610.3	10.44	0.58
Final	618.0	614.1	612.1	6.17	0.34
Change	10.0	6.8	1.8	5.24	0.24
Rib fat, mm					
Initial	3.8	4.2	3.7	0.25	0.33
Final	4.9	5.4	4.6	0.23	0.09
Change	1.1	1.5	0.8	0.21	0.12
Rump fat, mm					
Initial	4.5	4.9	3.9	0.37	0.21
Final	5.4	6.1	4.8	0.65	0.31
Change	1.1	1.5	0.8	0.81	0.37

[z]DDGS = cows supplemented with wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend); COMM = cows supplemented with commercial range pellet; CONT = cows received no supplement

[y]SEM = standard error of the mean

[x]Cow BW was adjusted for conceptus gain

A two year study by Kartchner (1980) found the effect of supplementation dependent on a number of factors, such as environmental conditions and forage quality and availability. Protein supplementation positively impacted cow performance when forage DMD was less than 50% and environmental conditions were less favourable (-2 to -38°C, heavy snow), limiting forage availability. When forage DMD was greater than 50% and environment was mild, there were no observed effects of protein or energy supplementation on cow performance. Average IVDMD of the stockpiled crested wheatgrass pasture was 56.4 percent in the current study and average temperature was 5.0°C (range -1.8 to 12.2°C). Greater differences in cow performance may have been observed if pasture forage quality had been lower or if environmental conditions had been more adverse.

Table 5 Effects of supplementation on body condition score (BSC) of beef cows grazing stockpiled pasture

	Treatment[z]				
BCS	DDGS	COMM	control	SEM[y]	P value
Start of trial (% of cows)					
2	31.0	20.7	20.0	0.23	0.57
2.5	41.4	51.7	50.0	0.28	0.71
3	24.1	24.1	23.3	0.23	1.00
3.5	3.4	3.4	6.7	0.11	0.80
4	0.0	0.0	0.0	0.00	1.00
End of trial (% of cows)					
2	6.2	0.0	6.2	0.09	1.00
2.5	28.1	37.5	46.9	0.25	0.35
3	43.8	43.8	40.6	0.26	0.96
3.5	18.8	28.0	6.3	0.22	0.38
4	3.1	6.2	0.0	0.07	0.85
Change (% of cows)					
-1	0.0	3.4	0.0	0.03	1.00
-0.5	3.4	0.0	6.7	0.08	0.86
0	31.0	24.1	46.7	0.26	0.23
0.5	41.4	48.3	40.0	0.27	0.80
1	24.1	17.2	6.7	0.20	0.27
1.5	0.0	6.9	0.0	0.05	1.00

[z]DDGS = cows supplemented with wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend); COMM = cows supplemented with commercial range pellet; CONT = cows received no supplement

[y]SEM = pooled standard error of the mean

iv) Economic analysis

Study economic analysis included feed and yardage costs associated with supplement strategy, pasture establishment costs, equipment use, fuel, and labour. Sufficient quantities of DDGS and commercial range pellet were secured for both years of the study in September 2007. The wheat-based DDGS (70:30 wheat:corn blend) was obtained from Husky Energy (Lloydminster, Saskatchewan, Canada) and quoted by Wilbur Ellis to be priced at $140 per tonne (September 2007). The commercial range pellet was custom blended by FeedRite Ltd (Humboldt, Saskatchewan, Canada) and cost $8.25 per 25 kg bag ($330 per tonne). Mineral and salt were purchased from FeedRite Ltd. (Humboldt, Saskatchewan, Canada) and priced at $24.47 per 25 kg and $4.75 per block in 2007 and $31.80 per 25 kg and $5.48 per block in 2008, respectively. A rate of $0.25 per head per day was used for the cost of stockpiled crested wheatgrass pasture for both years of the study; this rate

includes pasture repairs and depreciation (Saskatchewan Ministry of Agriculture (SMA) 2006). Labour was valued at $15.00 per hour. Equipment rates were obtained from SMA (2006).

Because expenses are magnified in small research trials due to increased costs associated with data collection and managing multiple groups of animals, trial costs are also presented to more accurately represent industry costs by extrapolating actual research costs to a model herd size of 200 head. To account for increased time, labour, and equipment use required to manage a larger herd, yardage costs were adjusted $0.50 per cow per day. Supplementation strategy costs are presented in Tables 7.

Table 6 Economics of managing beef cows on stockpiled crested wheatgrass pastures

	DDGS		COMM		CONT	
Item	2007	2008	2007	2008	2007	2008
	$ hd^{-1} d^{-1}					
Feed costs						
Supplement[z]	0.01	0.01	0.04	0.03	-	-
Mineral	0.01	0.03	0.01	0.03	0.01	0.03
Salt	-	-	-	-	-	-
Pasture	0.02	0.02	0.02	0.02	0.02	0.02
Total feed costs	0.05	0.06	0.07	0.08	0.04	0.05
Yardage costs						
Machinery cost (incl. fuel)	0.06	0.06	0.06	0.06	0.02	0.02
Labour	0.03	0.02	0.03	0.02	0.03	0.01
Total yardage costs	0.58	0.58	0.58	0.58	0.54	0.53
Total production costs	0.63	0.64	0.65	0.66	0.58	0.58

Average total costs were $0.64, $0.66, and $0.58 per head per day for DDGS, COMM, and CONT, respectively ($0.63, $0.65, and $0.58 per head per day in 2007 and $0.64, $0.66, and $0.58 per head per day in 2008 for DDGS, COMM, and CONT, respectively). Assuming daily pasture cost to graze cattle is equivalent to control cost, supplementing with either DDGS or commercial range pellet cost 10% or 13% more, respectively. Total cost differences between the two supplement strategies is reflective of the cost of the supplement. Because no difference ($P > 0.05$) in animal performance was observed between cows supplemented with either wheat-based dried distillers' grains with solubles or a commercial range pellet, producers may decide to supply wheat-based DDGS to their cows based solely on the current market cost of the supplement.

e) Conclusions and Recommendations

No significant differences were found in pasture forage utilization, forage intake, or beef cow performance between treatments. The lack of supplement effect on animal performance in this experiment may be attributed to the low experimental power, reducing the detection of significant differences. Furthermore, pasture quality in this trial was likely able to meet pregnant beef cow requirements, particularly if selective grazing was occurring. Providing supplement increased costs of production over the non supplemented groups as a result of increased feed costs, as well as yardage associated with delivering supplement. Supplementing beef cows with wheat-based DDGS resulted in no negative effects on cow performance in this study. Therefore, using DDGS as a supplement, based on these results will depend on the current market price of the potential supplements.

Effect of supplementing beef cows grazing barley crop residue with wheat-based dried distillers' grains with solubles on animal performance and intake

c) Methods

i) Study site

A 2 year winter grazing study was conducted at the Western Beef Development Centre's Termuende Research Ranch near Lanigan, Saskatchewan, Canada (51°51 'N, 105°02 'W). In late spring of each year (1 June 2007 and 29 May 2008) 25 hectares of forage barley (cv. Ranger) was seeded at a rate of 107.6 kg per ha with 56.1 kg per ha of actual nitrogen fertilizer. Crop weed control was managed using Round Up and Estaprop applied on 2 June and 11 June, respectively, in 2007 and Round Up and Buctril M were applied on 26 May and 25 June, respectively, in 2008. The barley was swathed 10 September 2007 and 8 September 2008 and combined to collect straw-chaff crop residue. Barley straw-chaff residue was collected in piles using a whole-buncher (AJ Manufacturing, Calgary, Alberta, Canada) unit attached to the combine. Average pile weight was 12.7 kg (dry matter basis). Chemical composition of the straw-chaff residue is presented in Table 8. Barley straw-chaff piles were divided into six 4 ha paddocks using high tensile electric fence.

ii) Grazing animal management

Forty-eight dry, pregnant (125±22 d) Black Angus cows (BW±SD; 629±8 kg) were managed on barley straw-chaff piles for 47 days (17 November 2007 to 2 January 2008) in 2007-08 and 46 days (14 November to 31 December) in 2008-09. Cows were allocated straw-chaff residue based on BW and feed nutrient density in accordance with the NRC (1996) beef model as predicted by CowBytes ration balancing program (Alberta Agriculture Food and Rural Development 1999). However, the amount of crop residue allotted varied depending on utilization and environmental conditions. Cow access to straw-chaff piles was controlled using temporary electric fence on a 3 d basis. Back-grazing was allowed, but not observed.

Each year, the same 48 Black Angus cows were used for Experiment I and Experiment II. After Experiment I, animals were stratified according to BW and days pregnant and re-allocated into 6 homogenous groups of 8. Cow groups were randomly allocated to 1 of 3 replicated (n=2) supplement strategies: (1) 100% wheat-based

dried distillers' grains with solubles (DDGS); (2) 50% DDGS and 50% rolled barley grain (50:50); or (3) 100% rolled barley grain (control; BARL). The DDGS was a 70% wheat, 30% corn blend provided by Husky Energy Ltd. (Lloydminster, Saskatchewan, Canada). In addition, medium quality hay (47.7% TDN; 7.1% CP; Table 8) was supplied to all cow groups during extreme winter conditions (> -25°C; 16 km wind) to minimize body condition loss. Chemical composition of the feedstuffs used in this trial is presented in Table 8. During the trial, cows received an average of 4.4 kg of supplement per day (28.5% of total dry matter intake (DMI); Table 9) or 0.7% of BW daily. The control diet (rolled barley grain) was formulated to meet beef cow maintenance requirements using CowBytes Ration Balancer Program (Version 4. Alberta Agriculture Food and Rural Development 1999). Wheat-based DDGS was then substituted 1:1 for barley grain for the DDGS and 50:50 diets. Supplements were fed daily between 0800 and 0900. During the trial, 68 g per cow per day of 2:1 mineral supplement (20.0% Ca, 10.0% P, 60 ppm Se, 70 ppm Co, 200 ppm I, 3000 ppm Cu, 9000 ppm Mn, 10 000 ppm Zn, 3700 ppm Fe, 1000 ppm F (max), 1 000 000 IU/kg Vitamin A (min), 150 000 IU/kg Vitamin D (min), 1000 IU/kg Vitamin E (min); FeedRite Ltd., Humboldt, Saskatchewan, Canada) and 78 g per cow per day of limestone (calcium carbonate, 38.0% Ca (actual); FeedRite Ltd., Humboldt, Saskatchewan, Canada) were top dressed on the supplements and cows had *ad libitum* access to cobalt-iodized salt (99.0% NaCl (min), 39.0% Na, 150 ppm I, 100 ppm Co). Water was supplied in troughs and portable windbreaks (10 x 16 m) were supplied for each group of cows.

Table 8. Chemical composition of forages and supplements

	Forage		Supplements	
Nutrient	Barley straw-chaff	Grass hay	DDGS[z]	Barley
DM (%)	83.9	76.5	90.0	89.1
CP (% DM)	8.6	7.1	38.5	13.8
NDF (% DM)	76.5	68.5	50.8	21.2
ADF (% DM)	50.1	48.1	19.8	8.1
ADL (% DM)	8.5	10.1	-	-
Phosphorus (% DM)	-	-	0.7	0.4
Sulfur (% DM)	-	-	0.8	0.3
NDIN (% N)	-	-	4.1	1.9
ADIN (% N)	16.1	14.4	-	-
IVDMD (% DM)	58.0	64.1	88.8	89.1
IVOMD (% DM)	59.7	66.5	91.7	94.1
TDN[y] (% DM)	45.4	47.7	80.0	93.3
DE[y] (Mcal kg^{-1} DM)	2.0	2.1	3.3	3.6

[z]DDGS = wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend)
[y]Calculated using the Penn State equations based on ADF (Adams 1995)

Parameters measured to evaluate cow performance included BW, BCS, and subcutaneous body fat thickness. Body weights were taken over 2 consecutive days at the start and end of trial and every 14 d throughout the course of the trial. Cow BW was corrected for conceptus gain using the equation from NRC (1996):

$$Conceptus\ weight\ (kg) = (calf\ birth\ weight \times 0.01828) \times e^{[(0.02xt) - (0.0000143xtxt)]}$$

Body condition score was determined by the same experienced technician at the beginning and end of the trial using the Scottish scale where 1=emaciated and 5=grossly fat (Lowman et al. 1976; Wildman et al. 1982). Ultrasound measurements of subcutaneous body fat thickness were determined between the 12th and 13th rib and at the thurl location using an Aloka SSD-500V ultrasound machine and Aloka UST-5044 probe (3.5 MHz). Guidelines for animal care (Canadian Council on Animal Care 1993) were followed at all times for all animals used in this experiment.

Table 9 Feed ingredient and nutrient composition of rations[z]

	Treatments[y]		
Item	DDGS	50:50	BARL
Predicted intake (kg DM/hd/d)	14.7	14.9	14.9
Feed	% of ration		
Barley Straw-Chaff	43.2	43.6	42.9
Hay	55.0	46.3	48.2
DDGS	28.1	14.4	-
Barley Grain	-	14.4	28.6
2:1 Mineral	0.5	0.4	0.4
Limestone	0.5	0.5	0.3
Salt	0.3	0.3	0.3
Chemical composition[x]			
CP (% DM)	19.8	15.8	11.4
NDF (% DM)	83.6	78.8	69.2
TDN (% DM)	68.4	70.6	69.4
DE (Mcal kg^{-1} DM)	2.9	3.0	2.9

[z]Rations formulated using CowBytes Beef Ration Balancer Program. Version 4. (Alberta Agriculture Food and Rural Development 1999)

[y]DDGS = cows supplemented with 100% wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend); 50:50 = cows supplemented with 50% DDGS and 50% barley grain; BARL = cows supplemented with 100% barley grain

[x]Calculated from average nutrient composition of ingredients.

iii) Estimation of forage utilization

Prior to the start of the winter grazing trial, 40 straw-chaff piles in each paddock were weighed. To determine forage utilization by the cows, straw-chaff residue from areas grazed at the start, middle, and end of the trial were weighed the following spring. The difference between the pre- and post-graze weight of straw-chaff piles was used to estimate daily forage intake by the cows (Volesky et al. 2002) using the following equation:

$$DMI\ (kg) = \frac{(kg\ DM\ p^{-1}\ allocated - kg\ DM\ p^{-1}\ residual)}{n^{-1} / p}$$

where p = the number of days per graze period and n = the number of cows per experimental unit.

iv) Laboratory analysis

Straw-chaff samples were collected at the start, middle, and end of the grazing trial. Hay samples were collected when hay supplementation started, and at the end of the trial. Forage DM was determined by drying the samples at 55°C for 72 h in a forced air oven. Prior to laboratory analysis, all forage samples were ground to pass through a 1-mm screen (Thomas-Wiley Laboratory Mill Model 4; Thomas Scientific, Swedesboro, NJ, USA). Representative supplement samples were also ground through a 1-mm screen using a Retsch ZM-1 grinder (Haan, Germany). All feed samples were analyzed for moisture, CP, ADF, NDF, IVDMD, and IVOMD and forages were analyzed for ADL and ADIN. Additionally, supplements were analyzed for phosphorus, sulfur, and NDIN. TDN (% DM) and DE (Mcal kg^{-1} DM) were calculated for forage samples using the grass-legume Penn State equation based on ADF and for supplement samples using the cereal grains Penn State equation (Adams 1995). Moisture was determined according to the procedure outlined by the AOAC (method #930.15; AOAC 2000). Crude protein (N x 6.25), NDIN, and ADIN concentrations were determined using the Kjeldahl procedure (method #984.13; AOAC 2000) using the 2400 Kjeltec Analyzer Unit (FOSS Tecator, Hoganas, Sweden). NDF and ADF were analyzed using an ANKOM 200 Fiber Analyzer (ANKOM Technology, Fairport, NY). NDF was analyzed without sodium sulfite in order to further determine NDIN content of the samples (Hertz and Mertens 1996). Lignin content was evaluated using the beaker method outlined by ANKOM Technology. *In vitro* dry matter digestibility and IVOMD was estimated using the filter bag technique (Daisy[II], ANKOM Technology Corporation, Fairport, NY). Artificial saliva was inoculated with rumen fluid strained through four layers of cheese cloth. Rumen fluid was collected from a ruminally-fistulated Holstein cow fed 70% silage and 30% concentrate (custom pellet; DM basis). Phosphorus and sulfur were analyzed according to the procedures outlined by Qian et al. (1994) and Kowalenko (1993), respectively.

v) Data analysis

The Proc Mixed Model procedure of SAS (2005) was used for all statistical analysis except body condition score. Differences were considered significant when $P < 0.05$; means were separated using Tukey's multi-treatment comparison method

(Saxton 1998). Cow BW and rib and rump fat were analyzed as fixed effects in a randomized complete block design with year considered as a random effect. The experimental model was:

$$Y_{ij} = \mu + \rho_i + \alpha_j + e_{ij}$$

where μ is the overall mean, ρ_i is the block or random effect to the *i*th year, α_j is the fixed effect of the *j*th treatment, and e_{ij} is the error term specific to the experimental unit (cow group) assigned to the *j*th treatment within the *i*th year.

Because cow body condition score data are discrete values with no unit cow body condition score data was analyzed using the Proc Glimmix procedure of SAS (2005). Proc Glimmix is used to fit statistical models to data with correlations or non-constant variability and where the response is not necessarily normally distributed (SAS Institute Inc. 2005).

Forage intake estimations were analyzed as a completely randomized design using the Proc Mixed procedure with data collected in 2008 only:

$$Y_{ij} = \mu + t_i + e_{ij}$$

where *i* is the treatment (supplementation), μ is the overall mean, t_i is the fixed effect to the *i*th treatment, and e_{ij} is the error term specific to the experimental unit (cow group) assigned to the *j*th treatment.

d) Results

i) Forage utilization

Estimated daily DM intake of barley straw-chaff residue was not affected ($P > 0.05$) by supplement program (Table 10). Average barley straw-chaff intake was 7.2, 6.9, and 7.5 kg per day ($P = 0.80$), or 1.14, 1.12, and 1.18% BW per day ($P = 0.92$) for DDGS, 50:50, and BARL supplemented cows, respectively. This level of intake is slightly lower than that predicted using NRC (1996) beef model in CowBytes, which estimated beef cows in the second trimester of pregnancy can consume 1.2% of BW as straw daily. Similarly, Males et al. (1982) reported beef cows consuming wheat straw, supplemented with barley grain and urea, consumed 1.2% BW as wheat straw. Forage intake can be affected by supplementation type, environment, and physiological status of the beef cow (Kartchner 1980; NRC 1996). In the current study, based on the calculated DE of the straw-chaff, cows would need to consume 11.8 to 12.9 kg of barley straw-chaff to meet calculated maintenance requirements of 8.87 to 9.72 Mcal of NE_m per day (NRC 1996). Because maximum intake of crop residue is approximately 1.2% BW (NRC 1996), or 7.6 kg for a 630 kg beef cow, an additional 3.18 to 4.03 Mcal of NE_m needs to be supplied to the animal daily. This additional energy was supplied as barley grain, DDGS, or both, thus meeting requirements but not affecting straw-chaff intake ($P > 0.05$). The extent to which supplementation can influence forage DMI is known as substitution rate (Bowman and Sanson 2000). The substitution rate of a supplement is affected by forage characteristics and availability, level and type of supplement, and physiological state of the animal (Allden 1981; Broster and Thomas 1981). Bowman and Sanson (2000) found a strong relationship between substitution rate and crude protein content of forage. Greater substitution rates have been observed for supplements with greater

Table 10 Estimated forage intake of beef cows grazing barley straw-chaff[z]

	Treatment[y]				Graze Period[x]				P value[w]		
Item	DDGS	50:50	BARL	SEM	1	2	3	SEM	trt	gp	trt*gp
Dry matter intake, kg d^{-1}											
Supplement	4.3	4.3	4.3	N/A	4.0	4.0	5.0	N/A	N/A	N/A	N/A
Hay	2.3	2.3	2.3	N/A	0.0	0.0	7.0	N/A	N/A	N/A	N/A
Straw-chaff	7.2	6.9	7.5	0.56	7.4	7.6	6.6	0.56	0.80	0.44	0.74
Total	13.8	13.5	14.0	0.54	10.9b	11.8b	18.5a	0.54	0.84	<0.01	0.66
Dry matter intake, %BW											
Supplement	0.69	0.70	0.67	N/A	0.57	0.67	0.82	N/A	N/A	N/A	N/A
Hay	0.35	0.38	0.36	0.011	0.00b	0.00b	1.09a	0.011	0.29	<0.01	0.31
Straw-chaff	1.14	1.21	1.06	0.105	1.17	1.21	1.06	0.105	0.92	0.61	0.73
Total	2.18	2.20	2.21	0.121	1.73b	1.88b	3.00a	0.121	0.98	<0.01	0.64

[z]Dry matter intake data analyzed by CRD for 2008 data only

[y]DDGS = cows supplemented with 100% wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend); 50:50 cows supplemented with 50% DDGS and 50% rolled barley grain; BARL = cows supplemented with 100% rolled barley grain

[x]Graze period: period 1 = 14 days; period 2 = 16 days; period 3 = 16 days

[w]trt = treatment effects; gp = graze period effects; trt*gp = treatment by graze period interaction

[a-b]Means with different letters in the same row are significantly different ($P < 0.05$) using Tukey's multi-treatment comparison method.

SEM = standard error of mean

concentrations of NSC and forages with low CP content (Meijs 1986; Faverdin et al. 1991; Bowman and Sanson 2000). Cereal grain supplementation is recognized to depress forage intake (Chase and Hibberd 1987; Zorrilla-Rios et al. 1991; Bodine and Purvis 2003; Bowman et al. 2004), however substitution as a result of barley grain supplementation was not observed in the current trial. In a review, Zorrilla-Rios et al. (1991) reported cereal supplementation greater than 20% of the diet had negative impacts on straw intake (Lamb and Eadie 1979; Gibb and Baker 1988), but if fed at less than 20% of the diet, straw intake was not affected or stimulated (Crabtree and Williams 1971; Fick et al. 1973; Mulholland et al. 1976; Leibholz and Kellaway 1984; Zorrilla-Rios et al. 1989). Average supplementation in 2008 was 32.5% (28.6% for both years) of the ration, based on CowBytes formulation program (1999), which could explain why estimated DMI was slightly lower than NRC (1996) predicted intake. However, similar forage intakes ($P = 0.80$) were observed for all treatment groups, indicating that barley grain and DDGS had comparable effects on forage intake.

While protein supplements are known to increase DMI of low quality forages (DelCurto et al. 1990b; Koster et al. 1996; Mathis et al. 1999; Olson et al. 1999), the high level of protein supplied by wheat-based DDGS in the current study had no effect ($P > 0.80$) on barley straw-chaff consumption. DelCurto et al. (1990b), Church and Santos (1981), and Beaty et al. (1994) have reported protein supplementation of low quality forages had a quadratic effect on forage dry matter intake. DelCurto et al. (1990b) supplemented pregnant cows grazing dormant tallgrass range with soybean meal-sorghum grain mixtures with increasing CP content at 0.5% BW daily. Church and Santos (1981) individually fed Holstein heifers chopped wheat straw and provided soybean meal daily to provide 0, 1, 2, 3, or 4 g CP per kg metabolic weight. Beaty et al. (1994) also fed wheat straw to ruminally fistulated steers while providing soybean meal-sorghum grain supplements with increasing CP concentration. All supplement strategies in the current trial supplied protein well in excess of CP requirements for mid-gestation beef cows. As such, protein supplementation may have exceeded the level where forage DMI would be improved. Total diet crude protein content was 19.6, 15.6, and 11.4% for DDGS, 50:50, and BARL treatments, respectively. Forage intake response to energy and protein supplementation has been shown to be variable. Zorrilla-Rios et al. (1991) reported that increasing supplemental corn linearly decreased ($P < 0.01$) intake of ammoniated wheat straw while supplemental corn gluten meal (CGM) had no effect on straw dry matter intake. DelCurto et al. (1990b) observed a positive quadratic intake response of dormant tall-grass forage to increasing levels of protein when supplemental energy was maintained. However, Beck et al. (1992) reported only a tendency ($P = 0.09$) for increasing supplemental crude protein levels to increase intake of ammoniated wheat straw when supplements were isocaloric. Church and Santos (1981) observed a quadratic increase of wheat straw consumption from soybean meal supplementation, however energy supplied by the supplement was also increased. The lack of supplement effect on straw-chaff DMI in the current study agrees with Winterholler et al. (2009), who reported forage intake was not different ($P = 0.10$) between late-gestation beef cows supplemented with wheat middlings and cottonseed meal, cottonseed meal-based supplement, or extruded, expelled cottonseed meal-based

supplements while grazing low quality tall-grass prairie hay. However, supplements in that experiment were isonitrogenous but had different energy values (70%, 80%, and 55% TDN, respectively). Dixon et al. (1981) reported barley straw intake was greater for steers supplemented with untreated canola meal than formaldehyde treated canola meal or fish meal, indicating an influence of the rumen degradability of the supplemental protein.

Estimated DMI of barley straw-chaff was not affected ($P > 0.05$) by grazing period (Table 10). Straw-chaff intake was anticipated to decrease when cows were supplemented with grass hay for 12 days during the final third of the trial in 2008. Hay supplementation began when straw-chaff intake was compromised by adverse weather and severe windchill factor (> 16 km h^{-1}; mean temperature -26.5°C). Grazing behaviour, as assessed by the herd person, was altered as the temperature decreased and wind chill factors came into effect. These observations agree with Adams et al. (1986) who reported daily grazing time decreased as mean temperature dropped. However, Prescott et al. (1994) did not observe significant fluctuations in grazing time with short term temperature stress in Montana, USA. Differences in grazing time may be affected by forage and shelter availability (Leaver 1985; Prescott et al. 1994), degree of acclimatization (Beverlin et al. 1989), photoperiod, or physiological state (NRC 1996). In this trial, a 1.0 kg per day decrease in straw-chaff intake was noted during the last 21 days of the trial. The minimal decrease in straw-chaff intake when supplemental grass hay was fed indicates either a lack of sensitivity of the forage intake estimation technique or an inability to differentiate between forage consumed and forage lost due to trampling or dispersal. The observed behaviour when the cows were first allowed access to straw-chaff piles was to sort through the piles and consume mainly chaff and grain residue. After the most palatable material had been consumed, cows would use the remaining straw for bedding. This activity caused great dispersal of material, plausibly causing loss that may have been mistakenly considered intake. This lack of sensitivity in the estimation technique may have compromised the detection of intake differences as affected by supplementation strategy.

ii) Cow performance

Cows supplemented with 100% DDGS or 50:50 DDGS:barley grain had greater ($P < 0.01$) positive BW change than cows supplemented with 100% rolled barley grain (Table 11). Cows supplemented with 100% DDGS, 50% DDGS: 50% rolled barley grain, or 100% rolled barley grain gained or lost an average of 11.3, 6.8, or -6.5 kg per head, respectively. These results agree with Beck et al. (1992), who reported cows supplemented with sorghum grain plus soybean meal had higher gains than those supplemented with equal levels of energy or protein as sorghum grain while consuming ammoniated wheat straw. Sanson et al. (1990) reported protein (0.72 kg TDN per day; 290 g protein per day) supplemented cows lost less weight than those receiving ear corn and protein (1.16 kg TDN per day; 290 g protein per day) or just ear corn (1.16 kg TDN per day; 127 g protein per day) while grazing native Sandhills winter range in Nebraska.

Zorrilla-Rios et al. (1991) reported the improvement in ADG for steers supplemented with CGM was greater than that calculated from the energy supplied by

the CGM supplement. The authors contributed the difference in ADG was attributed to the RUP content of the supplement which increased the total flow of protein to the small intestine (Egan 1981) and supplied limiting amino acids to the animal (Tamminga 1980; Oldham 1982). Nuez-Ortin (2010) reported the RUP content of 70% wheat, 30% corn blend DDGS was 63.8% of total crude protein. The digestibility of RUP in the small intestine could also affect cow performance. Although NRC (1996) assumes all RUP to be 80% digestible, MacDonald et al. (2007) found the digestibility of corn DDGS varied from 31 to 94 percent. Deficiencies in metabolizable protein (MP) are more likely to be met by more digestible RUP and animal performance is improved when MP requirements are met (MacDonald et al. 2007). Therefore, the greater ($P < 0.01$) positive BW change observed for cows supplemented with 100% or 50% DDGS may be due to the effects of RUP. Males et al. (1982) reported BW change was directly related to daily intake of digestible dry matter. In the current study, there was no difference ($P > 0.05$) detected in total dry matter intake between treatment groups, yet DDGS supplemented cows gained more weight.

Table 11 Effect of supplementation on beef cow performance

	Treatment[z]				
Item	DDGS	50:50	BARL	SEM	P value
Body weight[y], kg					
Initial	629.1	628.7	629.1	6.93	0.99
Final	640.4a	635.4ab	622.6b	5.85	0.04
Change	11.3a	6.8a	-6.5b	3.05	<0.01
Rib fat, mm					
Initial	4.8	4.8	5.3	0.23	0.29
Final	5.2	5.2	5.3	0.64	0.91
Change	0.4	0.5	0.0	0.78	0.62
Rump fat, mm					
Initial	5.0	5.6	5.7	0.77	0.77
Final	6.4	6.5	5.7	1.70	0.10
Change	1.5	1.0	0.1	1.16	0.10

[z]DDGS = cows supplemented with 100% wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend); 50:50 cows supplemented with 50% DDGS and 50% rolled barley grain; BARL = cows supplemented with 100% rolled barley grain

[y]Cow BW was adjusted for conceptus gain

[a-c]Means with different letters in the same row are significantly different ($P < 0.05$) using Tukey's multi-treatment comparison method. SEM = standard error of the mean

Differences in cow BW gains may be the result of forage intake differences that were undetected by the DMI estimation technique. Alternatively, these results may indicate a difference in the calculated verses actual energy value of the supplements. The TDN value used by CowBytes Ration Formulation program for barley and DDGS were 90% (NRC 1996) and 88% (ALS Central Testing, Saskatoon, SK), respectively. Therefore, supplements fed on a unit to unit basis were considered to have similar energy levels (Table 9). However, according to the wet chemistry analysis, barley grain has a higher DE content (3.97 Mcal kg^{-1}) than DDGS (3.42 Mcal kg^{-1}; Table 8) as calculated by the Penn State equations for cereal grains (Adams 1995). Therefore, greater performance would be expected from cows supplemented with barley grain. However, the opposite result was observed, suggesting a greater energy value for DDGS than calculated from laboratory analysis. Similarly, Gibb et al. (2008) reported that the NE_g of wheat DDGS was higher than the value predicted by the DM digestibility of DDGS. Other studies (Firkins et al. 1985; Larson et al. 1993; Ham et al. 1994; Trenkle 1997) have reported the energy content of corn-based distillers' products greater than the energy value of corn grain, resulting in greater animal performance. While protein is considered the most limiting nutrient of low quality forages (Kartchner 1980; DelCurto et al. 1990a; Freeman et al. 1992), studies have shown that gestating beef cows consuming low quality forages continue to lose BW and body condition in the winter feeding period even when protein requirements are met with concentrated protein supplements (Lusby et al. 1991; Marston et al. 1995; Banta et al. 2006; Steele et al. 2007). Conversely, Beck et al. (1992) reported that animal performance was improved when natural protein was supplemented despite protein requirements being met. The positive weight gain observed in the current study for cows supplemented with 100% or 50:50 DDSG:barley grain compared to cows supplemented with 100% barley grain further validates the value of DDGS as an energy supplement and protein supplement, regardless of which nutrient improves animal condition. Despite the change in cow BW, there were no differences ($P > 0.05$) in body fat between treatment groups, although there was a tendency ($P = 0.10$) for DDGS and 50:50 supplemented cows to gain more condition in the rump location compared to barley supplemented cows (Table 11). MacDonald et al. (1999) reported hip fat depth to be more variable than rib fat depth over time. Furthermore, ultrasound measurements taken at the hip location were a more accurate predictor of body condition than measurements taken at the rib location (MacDonald et al. 1999). There were no differences ($P > 0.05$) in BCS as a result of supplementation program (Table 12). This is not unexpected, as a BW change of 50 kg is required to detect a BCS change of 0.5 (Lowman et al. 1976). Winterholler et al. (2009) also reported no difference in BCS change as a result of variable energy and equal protein supplementation of beef cows consuming tall grass prairie hay in late gestation and early lactation. Similarly, Males et al. (1982) did not find differences in BSC change between cows grazing 100% alfalfa, combinations of alfalfa and wheat straw, or wheat straw supplemented with barley-urea.

Table 12 Effects of supplementation on body condition score (BSC) of beef cows grazing barley straw-chaff piles

	Treatment[z]				
BCS	DDGS	50:50	BARL	SEM[y]	P value
Start of trial (% of cows)					
2	6.2	3.1	9.4	0.13	0.62
2.5	59.4	75.0	50.0	0.25	0.18
3	34.4	18.8	21.9	0.23	0.36
3.5	0.0	3.1	18.8	0.10	0.26
4	0.0	0.0	0.0	0.00	1.00
End of trial (% of cows)					
2	3.1	6.5	3.1	0.11	0.77
2.5	50.0	54.8	59.4	0.26	0.76
3	46.9	35.5	31.2	0.26	0.45
3.5	0.0	3.2	6.2	0.07	0.86
4	0.0	0.0	0.0	0.00	1.00
Change (% of cows)					
-1	0.0	0.0	0.0	0.00	1.00
-0.5	9.4	12.9	23.3	0.04	0.34
0	65.6	58.1	50.0	0.05	0.49
0.5	25.0	29.0	23.3	0.05	0.87
1	0.0	0.0	3.3	0.01	1.00
1.5	0.0	0.0	0.0	0.00	1.00

[z]DDGS = cows supplemented with 100% wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend); 50:50 cows supplemented with 50% DDGS and 50% rolled barley grain; BARL = cows supplemented with 100% rolled barley grain
[y]SEM = pooled standard error of the mean

iii) Economic analysis

Economic analysis of supplement strategies included feed and yardage costs associated with supplement strategy, infrastructure establishment and removal costs, equipment use, fuel, and labour. The DDGS (70:30 wheat:corn blend) was obtained from Husky Energy (Lloydminster, Saskatchewan, Canada) in September 2007. Wilbur Ellis priced the DDGS at $140 per tonne in September 2007 and $175 per tonne in September 2008. Rolled barley grain was priced at $194.27 per tonne in November 2007 and $236.52 per tonne in November 2008. Mineral and salt were purchased from FeedRite Ltd. (Humboldt, Saskatchewan, Canada) and priced at $24.47 per 25 kg and $4.75 per block in 2007 and $31.80 per 25 kg and $5.48 per block in 2008, respectively. Barley straw chaff was valued at $0.048 per kg of DM for both years. Labour was valued at $15.00 per hour (Saskatchewan Ministry of Agriculture (SMA) 2006). Equipment rates were obtained from the SMA (2006). Because expenses are magnified in small research

trials due to increased costs associated with data collection and managing multiple groups of animals, trial costs are also presented to more accurately represent industry costs by extrapolating actual research costs to a model herd size of 200 head. To account for increased time, labour, and equipment use required to manage a larger herd, yardage costs were adjusted $0.50 per cow per day. Supplementation strategy costs are presented in Table 13. Average total costs were $0.77, $0.77, and $0.78 per head per day for DDGS, 50:50, and BARL, respectively ($0.81, $0.82, and $0.83 per head per day in 2007 and $0.72, $0.72, and $0.73 per head per day in 2008 for DDGS, 50:50, and BARL, respectively). The difference between the total costs between the two supplemented treatments is reflective of the price of the supplement. Therefore, producers may choose affordable supplements based on the current market value. However, because cows supplemented with DDGS had positive BW change ($P < 0.01$) compared to cows supplemented with barley grain, producers may consider using wheat-based DDGS as a supplement strategy for cows grazing cereal crop residue based on improved performance, as well as its cost benefits.

Table 13 Economics of wintering beef cows on barley straw-chaff

	DDGS		50:50		BARL	
Item	2007	2008	2007	2008	2007	2008
Feed costs[z]			$ hd^{-1} d^{-1}			
DDGS[y] supplement	0.05	0.06	0.02	0.03	-	-
Barley grain supplement	-	-	0.03	0.04	0.07	0.08
Grass hay	0.03	0.01	0.03	0.01	0.03	0.01
Mineral	0.01	0.01	0.01	0.01	0.00	0.01
Limestone	-	-	-	-	-	-
Salt	-	-	-	-	-	-
Barley straw-chaff	0.02	0.02	0.02	0.02	0.03	0.02
Total feed costs	0.11	0.11	0.12	0.11	0.13	0.12
Yardage costs						
Machinery cost (incl. fuel)	0.15	0.09	0.15	0.08	0.15	0.08
Labour	0.05	0.03	0.05	0.03	0.05	0.03
Total yardage costs	0.70	0.61	0.70	0.61	0.70	0.61
Total production costs	0.81	0.72	0.82	0.72	0.83	0.73

[z]Feed prices are presented in Appendix Table A.13
[y]DDGS = wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend)

e) Conclusions and Recommendations

When pregnant beef cows graze cereal crop residue in the winter, supplementation is necessary to meet daily nutrient requirements. No supplement effect ($P > 0.05$) was seen on forage DMI, possibly because differences were not detected by the estimation technique used. However, if forage intake was not altered by supplement strategy, straw-chaff consumption may have been equally depressed by the energy supplied by

each supplement or protein may have been overfed in all treatments such that forage intake improvements were not detected.

Cow BW change was greater ($P < 0.01$) for cows supplemented with 100% or 50% DDGS compared to cows supplemented with 100% barley grain. These improvements in cow BW suggest a greater energy content of DDGS than that estimated by laboratory wet chemistry techniques. This would suggest that DDGS supplied more energy than barley grain when fed on a 1:1 unit to unit basis. There are discrepancies in the literature as to whether improved animal performance can be attributed to energy or protein supplementation while cattle consume low quality forages. Regardless, DDGS is high in both protein and energy, and therefore has great potential as a supplement for beef cows grazing barley straw-chaff residue. A slight economic advantage was noted when DDGS was included in supplement program. Considering the improved performance of beef cows supplemented with DDGS as well as the price advantage on the initial commodity, wheat-based DDGS may prove advantageous for producers managing dry, pregnant beef cows on barley straw-chaff.

f) Acknowledgements

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g) Other

i) **Western Beef Development Centre Field Days** – Project results were presented to beef producers at the WBDC Field Days:

- WBDC Summer Field Day - June 24, 2008 (180 producers)
- WBDC Winter Field Day - December 2, 2008 (60 producers)

ii) **Articles written**

Cold Reality of Winter Feeding. Grain News - Cattlemen's Corner. Volume 35, No. 2. January, 2009.

Can You Supplement Winter Cow Diets With DDGS? Canadian Cattlemen. The Beef Magazine. pp. 26. Volume 71, No. 11. Fall, 2008.

Distillers Grain Tested on Termuende Ranch. The Western Producer. Volume 86, No. 14. July 3, 2008.

How Much Ethanol By-Product Can be Fed On The Ranch? Canadian Cattlemen. The Beef Magazine. Volume 70, No. 11. Fall, 2007.

iii) **WBDC Fact Sheets Published**

Van De Kerckhove A and **Lardner HA**. Effects of Supplementing Beef Cows Grazing Crop Residue with Dried Distillers Grains. WBDC FACT SHEET #2008-05 December 2008.

Van De Kerckhove A and **Lardner HA**. Effects of Supplementing Beef Cows Grazing Stockpiled Pasture with Dried Distillers Grains. WBDC FACT SHEET #2008-03 December 2008.

iv) **Journal Manuscript** (In Press)
Van De Kerckhove, AY, Lardner HA, Yu P, McKinnon JJ and Walburger K. 2010. Effect of wheat-based dried distillers' grain plus soluble on forage intake and digestibility, rumen passage rate and digestion and rate and extent of forage degradation. Can. J. Anim. Sci. (in press).

v) **Thesis Defense**
Amanda Van De Kerckhove successfully defended her Master of Science Thesis on April 13 2010

4) Optimizing the use of DDGS in beef growing and finishing rations

b) Introduction

The overall objective of this project was to provide the cattle feeding sector and the ethanol industry with detailed information on the feeding value of wheat-based dried distillers' grains with solubles (DDGS) in backgrounding and finishing rations such that domestic and international markets can be developed.

The specific objectives of this project are:

- To identify nutrient digestibility of DDGS for ruminants;
- To develop feeding recommendations that optimize the use of DDGS in low-cost backgrounding programs;
- To develop feeding recommendations that incorporate DDGS in finishing rations and to assess the potential of this feed ingredient for reducing the incidence of acidosis and other digestive problems associated with finishing diets.

c) Methods

Nutrient digestibility coefficients (ADF, NDF, fat, protein, and energy) and digestible energy values for DDGS were determined by total tract fecal collection experiment using lambs. A total tract digestibility trial comparing barley grain and 100% wheat DDGS was carried out in October 2007. Twenty-one lambs (initial weight 35.0 ± 4.6 kg) were randomly assigned to seven treatment groups for a 21-day total tract digestibility trial. The seven treatment diets consisted of a control diet of 100% barley silage, and six experimental diets containing 25, 50 or 75% barley pellet and 25, 50 or 75% wheat DDGS pellet. Daily feed and fecal samples were collected from individual lambs, analyzed for nutrient content, and used to determine the total tract digestibility of each experimental diet. Samples of feed and feces were analyzed for moisture (method 930.15; AOAC, 1990), crude protein by the Kjeldahl method of N-determination (method 984.13, AOAC, 1990), crude fat by diethyl ether extraction (method 920.39; AOAC, 1990), and neutral (NDF) and acid (ADF) detergent fibre using the Ankom 200 fibre analyzer (Ankom Technology, NY) with the use of α-amylase in the NDF procedure. Gross energy was determined using a bomb calorimeter (Parr, Moline IL, USA). The total tract digestibility of each nutrient

(DM, CP, ADF, NDF, EE, gross energy) was determined from the total feed intake and total fecal output. Apparent nutrient digestibility coefficients were calculated as the difference between nutrient intake in feed and nutrient excretion in fecal material.

Further metabolism trials with steers will be conducted using the indicator method to determine nutrient digestibility and energy values of DDGS for cattle. Beef feedlot trials with steers will be carried out to evaluate the inclusion of DDGS in these rations as a replacement for barley grain in both backgrounding and finishing rations. In each of 2 years, weaned claves will be fed at the University of Saskatchewan Beef Cattle Research Unit. Dietary treatments will include a varying amount of DDGS as replacement for barley in the backgrounding and finishing rations. The intent will be to find an optimal inclusion level of DDGS which maximizes its use in meeting the protein and energy requirements of the cattle.

d) Results

Results of the total tract digestibility determination are shown in Tables 1 & 2. Dry matter intake of lambs increased linearly ($P<0.05$) as the inclusion of DDGS in the diets increased (Table 4), whereas the DMI of barley diets increased in a quadratic fashion ($P<0.05$). Intake of barley diets declined as barley inclusion increased from 50 to 75%, possibly due to the increased level of starch.

The digestible energy content of treatment diets increased linearly ($P<0.05$) with increasing DDGS inclusion. Conversely, digestible energy content determined by total tract digestibility measurement was not different between the control and the three diets containing barley grain. As with dietary gross energy, the DDGS diets exhibited greater digestible energy than their counterpart barley-based diets, despite containing lower starch and higher fiber content. As noted by Klopfenstein et al (2008), the paradox of DDGS is that it appears to have greater feeding value than the grain it is produced from, yet is less digestible because of the high fiber content. digestibility coefficients for NDF were greater ($P<.0001$) for the 50DG and 75DG diets (576 and 524 g kg^{-1}, respectively) compared to the 50 and 75% barley diets (421 and 384 g kg^{-1}, respectively). This indicates that despite the fact that DDGS contains a greater overall content of fiber than barley, it is more digestible and provides more energy value than barley fiber. Similarly, the ADF digestibility of the 50% DDGS diet was 564 g kg^{-1} compared to only 428 g kg^{-1} for the 50% barley diet ($P<0.05$). The digestibility of DM or CP between DDGS and barley-based diets was not significantly different, indicating that DDGS provides equally digestible DM and CP to barley at various inclusion levels. In terms of fiber digestibility, diets including DDGS exhibited greater digestibility of NDF at both 50 and 75% inclusion rate.

Table 1. Summary of dry matter intake and total tract digestibility of dietary nutrient fractions of DDGS diets fed to lambs. Orthagonal polynomial contrasts (linear and quadratic) among the DDGS treatments are shown.

	Dietary Treatment					P-value		P-value
Item	Control	25DG	50DG	75DG	SEM	Trt	**	Regression
Voluntary DMI, g d^{-1}	899 b	1426 a	1678 a	1629 a	137.4	0.0026	linear	0.0007
Digestibility of nutrient fractions (%)								
Dry matter	66.7 b	69.5 ab	72.9 a	72.4 a	1.4818	0.026	linear	0.0053
EE	66.9 c	76.1 b	79.5 ab	82.6 a	1.476	<.0001	linear	<.0001
CP	65.0	67.0	75.6	71.9	3.761	0.213	–	–
NDF	61.2 a	60.4 a	57.6 ab	52.4 b	1.899	0.015	linear	0.0026
ADF	58.9	59.9	56.4	49.9	3.08	0.131	–	–
Digestible Energy, Mcal kg^{-1}	2688 c	2974 b	3286 a	3409 a	64.25	<.0001	linear	<.0001

Table 2. Summary of dry matter intake and total tract digestibility of dietary nutrient fractions of barley diets fed to lambs. Orthagonal polynomial contrasts (linear and quadratic) among the barley treatments are shown.

	Dietary Treatment					P-value		P-value
Item	Control	25BG	50BG	75BG	SEM	Trt	**	Regression
Voluntary DMI, g d^{-1}	899 b	1254 a	1420 a	1199 a	88.1	0.0041	quadratic	0.0039
Digestibility of nutrient fractions (%)								
Dry matter	66.7	70.6	67.7	71.6	1.955	0.2658	NS	NS
EE	66.9	71.6	67.2	70.5	3.517	0.7254	NS	NS
CP	65.0	69.0	72.5	73.6	2.86	0.1728	linear	0.0331
NDF	61.2 a	57.4 a	42.1 b	38.4 b	3.574	0.0003	linear	<.0001
ADF	58.9 a	56.2 a	42.8 b	42.4 b	4.188	0.0167	linear	0.0031
Digestible Energy, Mcal kg^{-1}	2688	2888	2770	2958	85.14	0.1478	NS	NS

e) Conclusions and Recommendations

The results of this study indicate that wheat-based DDGS provide a good source of digestible energy, protein and fiber for ruminant animals. Despite its lack of starch and greater proportion of fiber, wheat DDGS has an energy value comparable or greater to that of barley grain at equal levels of dietary inclusion.

Comparison of wheat or corn dried distillers grains with solubles on performance and carcass characteristics of feedlot steers

b) Introduction

Growth of the ethanol industry has resulted in large increases in the supply and use of dried distillers grains with solubles (DDGS) in livestock rations. With regards to feedlot cattle, there has been a significant amount of research on the feeding value of corn-based DDGS as both a protein and energy source, and its associated effects on carcass traits (Ham et al. 1994; Klopfenstein et al. 2008). In terms of the energy value of corn distillers grains with solubles, Larson et al. (1993) observed that wet distillers grains with solubles (WDGS) when fed at levels ranging from 5.2 to 40% of DM, averaged 2.53 and 1.96 Mcal kg^{-1} NEg, when fed to yearlings and calves, respectively. These values averaged 169 and 128% the NEg value of dry rolled corn. Ham et al. (1994) reported that corn WDGS and DDGS fed at 40% of the ration resulted in NEg values of 2.16 and 1.87 Mcal kg^{-1}, respectively, an increase of 39 and 21% relative to corn grain. In finishing rations, corn DDGS has been successfully fed up to 40% of dietary DM, however, recent studies have suggested that inclusion at 20 to 25% of the ration DM optimizes feed efficiency in finishing cattle (Benson et al. 2005; Buckner et al. 2008).

Relative to corn DDGS, there have been relatively few studies that have examined the feeding value of wheat DDGS. Boila and Ingalls (1994) examined the digestibility of wheat DDGS and concluded that wheat DDGS is a good source of rumen bypass protein (63.5%, ruminally undegraded nitrogen). With respect to the inclusion of wheat DDGS as an energy source (>15% of diet DM), the replacement of rolled barley with wheat DDGS at 25 and 50% of the ration in backgrounding diets increased ADG and improved feed efficiency (McKinnon and Walker, 2008). Diet NEg was 8.2% higher in diets supplemented with DDGS relative to a control barley-based diet (McKinnon and Walker, 2008). Beliveau and McKinnon (2008) found no effect on ADG, feed efficiency or DMI with the substitution of up to 23% wheat DDGS for rolled barley in the finishing rations. Gibb et al. (2008) observed that finishing cattle fed wheat DDGS up to 60 % of the diet had linear increases in DMI, similar ADG and subsequently poorer feed efficiency as wheat DDGS inclusion rate increased.

With respect to carcass quality, cattle fed corn DDGS have been shown to have reduced marbling scores, particularly when fed at levels greater than 23% of the diet (Reinhardt et al. 2007). Klopfenstein et al. (2008) using meta-analysis, reported a linear increase in yield grades and a trend for a linear decrease in marbling scores when corn DDGS comprised 40% of the diet DM. In contrast, studies with wheat DDGS have not reported an adverse effect on carcass quality (Beliveau and McKinnon, 2008) other than a quadratic increase in subcutaneous fat thickness (Gibb et al. 2008).

As the supply of both wheat and corn DDGS increases, there is potential for these two byproducts to compete as feedstuffs. To date, there has been no direct comparison on the relative feeding value of these feeds in finishing cattle diets. Therefore, the objectives of this trial were to compare the performance and carcass quality of steers fed wheat DDGS relative to that of cattle fed corn DDGS in feedlot finishing rations.

c) Methods

All cattle utilized in this study were cared for under Canadian Council of Animal Care guidelines (CCAC 1993). Two hundred and seventy five crossbred steers were purchased, and shipped to the Beef Cattle Research Station at the University of Saskatchewan. Upon arrival, all steers were tagged and treated for internal and external parasites with Ivomec™ (Merial Canada Inc., Baie d'Urfé, QC, Canada). The cattle were vaccinated against clostridial diseases with Covexin 8™ (Schering-Plough, Kirkland, QC, Canada), *Pasteurella haemolytica* and *Histophilus somni* with Somnu-Star Ph™ (Novartis, Mississauga, Ontario) and infectious bovine rhinotracheitis, bovine viral diarrhea (types 1 and 2), Parainfluenza type 3 virus, and bovine respiratory syncytial virus with Biostar, Starvac 4 Plus™ (Novartis, Mississauga, Ontario). All cattle were fed a barley-based backgrounding ration (38.3% barley silage, 30.2% grass hay, 23.7% rolled barley grain and 7.8% supplement, DM basis) from arrival to the start of the trial.

Steers were weighed (376±24 kg, mean±SD) and implanted with a TBA-Estradiol combination implant (Synovex Choice™) (Wyeth Animal Health, Guelph, ON, Canada) at the start of the finishing trial. The steers were randomly assigned to one of 25 outdoor pens (n=5) with each pen randomly assigned to one of 5 treatments in a completely randomized design. The trial had a target end-point of 645 kg live weight (unshrunk basis) at which time the cattle were sent for slaughter.

i) Treatments & Dietary Composition

At the start of the trial, an 8-step diet adaptation was used to adapt the steers over a 21-day period from the backgrounding diet to the final finishing rations. The control diet was composed of 86.6% rolled barley grain, 5.7% supplement and 7.7% barley silage (DM basis) (Table 1) and was formulated to 12% CP and 1.95 and 1.30 Mcal kg^{-1} NE_m and NE_g, respectively. The four treatments included replacement of barley grain with 20 or 40% wheat or corn DDGS (DM basis) (Table 3.1). Rations were formulated to meet or exceed NRC (2000) requirements for CP, trace minerals and fat-soluble vitamins (Table 1). The calcium:phosphorus ratio was formulated to range from 1.5:1 to 2:1 with limestone added to the supplement as the DDGS content of the ration increased. Monensin sodium was fed at 27 mg kg^{-1} (DM basis) (Elanco Animal Health, Guelph, ON) in all diets.

The barley silage (AC Rosser) used in the study was grown at the University of Saskatchewan, harvested and stored in plastic bags (Ag-Bag, Miller-St. Nazianz, Inc., St Naziance, WI). Barley silage samples were taken every two weeks with the dry matter (DM) content recorded and used to adjust daily feeding amounts as necessary. Barley grain (61.1±2.1 kg hL^{-1}, mean±SD) was purchased from commercial grain sources and dry rolled on site (RossKamp Champion, Waterloo, IA). The wheat DDGS was supplied by Noramera BioEnergy Corporation (Weyburn, SK) while the corn DDGS was purchased from ConAgra Foods (Omaha, NE). Bunk samples of the total mixed ration were collected every two weeks from each pen, while barley, DDGS (wheat and corn) and supplement samples were taken as each load was received.

ii) Data Collection & Analysis

Cattle were fed *ad libitum* with feed being delivered twice daily in two equal allotments. The amount of feed delivered to each pen was recorded daily. Every two

weeks, the bunks were cleaned and any orts were weighed and discarded. Actual dry matter intakes for the pen were calculated based on the dry matter delivered to the bunk and corrected for any orts that were recorded every two weeks. Animals were weighed every two weeks, prior to the morning feeding. Ultrasound subcutaneous fat (USFAT) measurements were taken every 4 weeks in conjunction with a weigh day according to the procedure of Bergen et al. (1997) using an Aloka 500 V real-time ultrasound machine and a 17-cm linear array transducer. As the steers approached their target end weight, USFAT were taken every 2 weeks in accordance with weigh days. Ultrasound *longissimus dorsi* (USLD) measurements were taken at the start and end of the trial to calculate *longissimus dorsi (l. dorsi)* area gain. Net energy content of the diet was calculated according to Zinn and Shen (1998) as outlined by McKinnon and Walker (2008).

One hundred and seventy four of the steers were slaughtered at XL Beef Inc. in Moose Jaw, SK. The steers were shipped the day prior to the kill date and held overnight in lairage. Hot carcass weight (HCW) was obtained immediately after slaughter. After 24 h, carcasses were knife ribbed between the 12^{th} and 13^{th} ribs and carcass data (subcutaneous fat thickness, marbling score, *l. dorsi* area, estimated lean yield and any off-grades) was collected by Canadian Beef Grading Agency graders. Marbling scores were based on a 10 point system with 1=very abundant, 5=moderate, 7=small and 10=devoid. Liver abscess scores were subjectively measured using the Elanco classification system, as modified by McKinnon et al. (1992).

A subset of the steers (n=100) was slaughtered at the Agriculture and Agri-Food Canada Lacombe Meat Research Center (Lacombe, AB). The steers were shipped in 5 groups of 20 with 4 steers per treatment per load. Each load was shipped the day prior to the kill day and held overnight in lairage. Hot carcass and all viscera weights were recorded immediately after slaughter. Carcasses were chilled for 24 h after which Canadian Beef Grading Agency Graders collected carcass data as per the protocol used for commercial slaughter. Carcass front and hind weights were determined by separating the left side of the carcass between the rib and loin sections. Both the front (24 h postmortem) and hind (48 h postmortem) quarters of the left side of each carcass were partitioned into sub-primal boneless boxed beef (SPBBB) and waste (fat and bone). The SPBBB was trimmed according to the Canadian Meat Council (2000) with the edible trim partitioned to 65 or 85% lean. To determine the fat content of the trim piles, the trim piles were each ground three times (Butcher Boy Meat Grinder Model TCA22 with a 3.18-mm grind plate, Lasar Manufacturing Co., Ayrshire, UK), mixed thoroughly and a 100 g sub-sample was dried in a mechanical convection oven (VWR Scientific Model 1370FM, Mississauga, ON) at 105°C for 24 h to determine moisture content. Free oil in the dried sample was decanted and weighed. The remaining dried product was pulverized and two 4 g sub-samples were extracted in petroleum ether using a Tecator Soxtec Extraction System Model 2050 (Foss Analytical AB, Hoganas, Sweden). Total crude fat in the sample was determined as the weight of the oil decanted plus the percentage of fat in the dried sample. Once the total crude fat analysis was recorded, lean trim was adjusted to the appropriate fat content (65 or 85%) by the addition or removal of extracted fat.

iii) Chemical Analysis

All forage and bunk samples were dried in a forced air oven at 55°C for 72 h. Dried forage samples were ground through a hammer mill fitted with a 1 mm screen (Christy & Norris 8" Lab Mill, Christy Turner Ltd. Chelmsford, UK). Bunk samples were dried on a pen basis and composited by treatment for each 2 week collection period. Bunk and concentrate samples were ground through a 1 mm screen using a Retsch ZM100 grinder (Haan, Germany). Composite total mixed ration samples were analyzed in duplicate according to the Association of Official Analytical Chemists (2000) for DM by drying at 135°C (AOAC method 930.15), CP (AOAC method 948.13), NDF treated with amylase and without the addition of sodium sulphite (AOAC method 2002.04), ADF (AOAC method 973.18) and ether extract (AOAC method 920.39). Calcium and phosphorus were analyzed using the dry ashing procedure (AOAC methods 927.02 and 965.17, respectively). Calcium was determined using an atomic absorption spectrophotometer (Perkin-Elmer, Model 2380, CN, USA) while phosphorus was read at 410 nm on a spectrometer (Pharmacia, LKB-Ultraspec III, Stockholm, Sweden).

Each batch of wheat (N=2) and corn (N=2) DDGS were analyzed by Cumberland Valley Analytical Services (CVAS, Hagerstown, MD) according to the Association of Official Analytical Chemists (2000). Samples were analyzed for DM by drying at 135°C (AOAC method 930.15), CP (AOAC method 990.03) using a Leco FP-528 Nitrogen Combustion Analyzer (Leco, St Joseph, MI), ADF (AOAC method 973.18), ADIN (using ADF residue and Leco FP-528 Nitrogen Combustion Analyzer, Leco, St Joseph, MI), ash (AOAC method 942.05) and fat using a tecator extraction unit (AOAC method 2003.05). The methods of Van Soest et al. (1991) were used to analyze NDF content and the NDF residue was used for NDIN analysis (Leco FP-528 Nitrogen Combustion Analyzer, Leco, St Joseph, MI).

iv) Statistical Analysis

Data was analyzed as a completely randomized design, with pen as the experimental unit and treatment as a fixed effect using the Mixed Model procedure of SAS (Version 9.1; SAS Institute, Inc. Cary, N. C.). Satterthwaite's approximation on degrees of freedom was used with a Kenward-Roger adjustment on standard errors. Results were analyzed using a protected F-test ($P < 0.05$). Polynomial contrasts were used to determine the linear and quadratic effects of wheat or corn DDGS inclusion rate. Significant results ($P \leq 0.05$) were presented using slope (linear) or local maxima/minima (quadratic) for the best fit polynomial regression equation. Marbling and liver abscess score data were analyzed using the GLIMMIX macro (SAS, Version 9.1; SAS Institute, Inc. Cary, N. C.) with a binomial error structure and logit data transformation.

Table 1. Composition and analysis of control and wheat and corn dried distillers grains with solubles (DDGS) rations

	Treatment				
		Wheat DDGS		Corn DDGS	
	Control	20%	40%	20%	40%
Diet Composition (% DM basis)					
Barley silage	7.7	7.6	7.5	7.6	7.6
Barley grain	86.6	66.3	47.1	66.4	47.2
Wheat DDGS	0.0	20.4	39.7	0.0	0.0
Corn DDGS	0.0	0.0	0.0	20.3	39.5
Supplement	5.7	5.7	5.7	5.7	5.7
Supplement composition (% DM basis)					
Barley	13.3	44.4	38.4	44.4	38.4
Canola meal	36.6	0.0	0.0	0.0	0.0
Limestone	21.8	30.4	36.6	30.4	36.6
Vitamin premix[z]	10.6	10.5	10.4	10.5	10.4
Ionophore premix[y]	7.7	7.6	7.6	7.6	7.6
Trace mineral salt[x]	7.1	7.1	7.0	7.1	7.0
Canola oil	1.9	-	-	-	-
Urea	1.0	-	-	-	-
Ration Analysis (% DM basis±SE)					
Crude protein	12.1 ± 0.22	15.8 ± 0.32	20.9 ± 0.37	15.2 ± 0.14	18.3 ± 0.13
Ether extract	2.0 ± 0.07	2.1 ± 0.06	2.5 ± 0.06	3.8 ± 0.09	6.2 ± 0.12
Acid detergent fiber	7.9 ± 0.60	9.3 ± 0.48	12.2 ± 0.62	9.2 ± 0.45	11.3 ± 0.59
Neutral detergent fiber	22.5 ± 0.96	23.6 ± 0.95	25.0 ± 0.90	24.2 ± 0.68	26.8 ± 0.61
Calcium	0.6 ± 0.03	0.7 ± 0.06	0.95 ± 0.05	0.7 ± 0.42	0.8 ± 0.04
Phosphorus	0.4 ± 0.01	0.5 ± 0.01	0.6 ± 0.02	0.5 ± 0.01	0.6 ± 0.01

[z] University of Saskatchewan vitamin A & D supplement= 440,500 IU vitamin A, and 88,000 IU vitamin D_3 kg^{-1}

[y] University of Saskatchewan Feed Unit Ionophore Premix: Contains 96.77 % barley and 3.23 % Rumensin® Premix containing monensin (as monensin sodium) at 200 g kg^{-1} (Elanco, Guelph, ON) (DM basis)

[x] Trace mineral salt: 95 % NaCl, 12 000 ppm Zn, 10 000 ppm Mn, 4000 ppm Cu, 400 ppm I, 60 ppm Co, 30 ppm Se

d) Results

The wheat DDGS utilized in this study averaged 39.3±1.2% CP, 3.9±0.4% EE, 41.4±0.9% NDF, 16.6±3.5% ADF, 23.6±2.0% ADIN (% N), 0.12±0.01% Ca and 0.97±0.12% P (mean±SE, DM). The CP, EE and NDF values for the wheat DDGS were similar to that previously reported (Beliveau and McKinnon 2008; McKinnon and Walker 2008). The ADF level in the wheat DDGS used in this study was higher than that reported by Beliveau and McKinnon (2008) (13.2%) but similar to Gibb et al. (2008) (19.5%). The ADIN content was considerably higher than that reported by Beliveau and McKinnon (2008) (10.5% N) and Gibb et al. (2008) (10.5% N). The high ADIN value of the wheat DDGS could reduce the nitrogen digestibility of the diet, although Nakamura et

al. (1994) found a poor correlation between ADIN levels of DDGS and N digestibility. Furthermore, Kleinschmit et al. (2006) found no change in the feed efficiency of dairy cows fed a high ADIN (23.1% N) corn DDGS relative to those fed a low ADIN (9.4 and 10.3% N) corn DDGS.

The corn DDGS fed in this study averaged 31.8±0.1% CP, 13.7±0.7% EE, 43.8±0.5% NDF, 11.5±0.2% ADF, 11.6±0.1% ADIN (% N), 0.03±0.01% Ca and 0.89±0.01% P (mean±SE, % DM). The CP and NDF levels for the corn DDGS are comparable to previous findings (Spiehs et al., 2002). However the ADF levels are somewhat lower than those reported by Spiehs et al. (2002) (13.8 to 18.5%) and Kleinschmit (2007) (14.7 to 20.3%). The EE value for corn DDGS was slightly higher than previous reports of 10 to 12% by Spiehs et al. (2002) but comparable to the 13.9% reported by Gunn et al. (2009).

Substituting wheat or corn DDGS at 20 and 40% of the ration (DM basis) for barley increased CP content of the diets from 12.1% in the control diet to 15.8 and 20.9% in the 20 and 40% wheat DDGS diets and 15.2 and 18.3% for the 20 and 40% corn DDGS diets, respectively. In agreement with other studies (Benson et al. 2005; Beliveau and McKinnon 2008) ADF, NDF and P values (Table 1) increased with increasing level of wheat and corn DDGS in the diet. The EE content of the diet increased substantially with the addition of corn DDGS (2.0% in the control diet vs. 3.8 and 6.2% in the 20 and 40% corn DDGS rations, respectively). The EE content of the diet was not affected greatly by the inclusion of wheat DDGS (2.1 and 2.5% in the 20 and 40% rations, respectively).

i) Finishing Performance

Dry matter intake showed a differential response for cattle fed wheat or corn DDGS (Table 2). DMI increased ($P<0.01$) in a quadratic fashion ($y=10.358-0.027x+0.001x^2$, $R^2=0.73$, SEP 0.212) as wheat DDGS increased in the ration while DMI decreased ($P=0.01$) in a quadratic fashion ($y=10.358+0.027x-0.002x^2$, $R^2=0.88$, SEP 0.295) with increased corn DDGS levels. Solving the equation for wheat DDGS gives a local minima for DMI at a 13% inclusion rate with intake increasing as wheat DDGS increases to the 40% inclusion level. Beliveau and McKinnon (2008) noted a similar response to the current trial with cattle fed wheat DDGS up to 32% (DM) in a backgrounding trial. In contrast, these authors found no effect of wheat DDGS (up to 23% of the diet, DM) on DMI in finishing cattle. Gibb et al. (2008) observed a linear increase in DMI as wheat DDGS increased to 60% of the ration DM. These workers hypothesized that the increase in DMI was a compensatory response to a reduction in digestibility with increasing wheat DDGS as digestibility of the diet was reduced by 9.8% when wheat DDGS comprised 60% of diet DM.

There was no treatment effect ($P=0.13$) on ADG, although numerically cattle fed 40% wheat DDGS had the highest ADG (Table 2). This lack of significance is somewhat surprising as these cattle consumed more feed than the control cattle. However, calculated NEg based on performance was not different ($P>0.05$) between the control diet and the two wheat DDGS diets. Cattle fed wheat DDGS exhibited a linear decrease ($P=0.04$) in days on feed ($y=170.63-0.375x$, $R^2=0.43$, SEP 7.59) as concentration of wheat DDGS increased in the diet. This is likely a reflection of the increased DMI ($P<0.01$) and numerically higher ADG of the wheat DDGS fed steers, particularly those fed 40% wheat DDGS. The intake and ADG responses of the wheat DDGS fed cattle also explains why there was no effect of wheat DDGS inclusion level on gain:feed (Table 2).

Beliveau and McKinnon (2008) reported similar results for ADG and gain:feed for finishing cattle fed up to 23% wheat DDGS. Gibb et al. (2008) found that DMI increased linearly with increasing levels of wheat DDGS in the diet (up to 60%) with no effect on ADG. As a result, these workers reported that gain:feed ratios decreased with increasing levels of wheat DDGS.

In contrast, cattle fed corn DDGS exhibited a quadratic decrease (P=0.01) in DMI as inclusion levels increased (Table 2). Solving the quadratic equation gives a local maxima for DMI at the 8.0% corn DDGS inclusion level. Eun et al. (2009) also found that replacing rolled barley with corn DDGS (up to 18.3%, DM) in finishing rations resulted in reduced DMI, with the lowest DMI at the highest DDGS inclusion level. The decrease in DMI associated with feeding corn DDGS in barley rations could be due to the increasing dietary fat level associated with diets that contain corn DDGS. Ether extract levels reached 6.2±0.12% on the 40% corn DDGS diet (Table 1). Zinn and Jorquera (2007) recommended a maximum dietary fat intake of 6 to 7% in high concentrate rations to prevent DMI depression. Allen et al. (2009) suggests that elevated serum fatty acid concentrations, particularly unsaturated fatty acids may have a satiety effect in accordance with the hepatic oxidation theory. This theory states that food intake is controlled by the hypothalamus, which in turn is alerted to the body's energy status by the degree of hepatic oxidation of a variety of metabolic fuels. However, this theory does not explain why DMI is not reduced when corn DDGS is fed in corn-based rations. For example, Buckner et al. (2008) did not find any effect on DMI when corn DDGS replaced corn grain at levels up to 40% (DM basis). Dietary fat levels reached 6.3%. Benson et al. (2005) reported a quadratic increase in DMI when corn DDGS replaced corn grain at levels up to 35% of the diet DM, with dietary fat levels reaching 7.3%.

Differences in the energy content of the two cereal grains may account for differences in the DMI observed in finishing diets containing corn DDGS. Barley contains 1.40 Mcal kg^{-1} NEg whereas corn has 1.55 Mcal kg^{-1} of NEg (NRC 2000). In the present study, it is logical to assume that cattle fed the barley based control diet were eating to meet their energy needs and thus were gaining at or close to their genetic potential. In this case, substituting corn DDGS with a higher NEg value for barley should result in reduced DMI, as observed (Table 2). In contrast, in studies where corn DDGS has replaced corn, differences in NEg content are not as great and thus large changes in DMI would not be expected.

As with wheat DDGS, there was no effect (P=0.13) of corn DDGS inclusion level on ADG (Table 2). This is in contrast to Ham et al. (1994) and Buckner et al. (2008) who noted higher gains on cattle fed corn DDGS relative to those fed a corn-based ration. The lack of response in ADG is consistent with the reduced DMI of the corn DDGS fed cattle as discussed above. Cattle fed corn DDGS exhibited (P<0.01) a quadratic increase in gain:feed (y=0.1564–0.0003x+0.00003x^2, R^2=0.95, SEP 0.004) with a local minima at the 4.6% inclusion level. These results support Larson et al. (1993) who reported cattle fed corn WDGS at 40% of the ration had a 20% improvement in gain:feed. Ham et al. (1994) also reported similar results for both corn WDGS and DDGS. Klopfenstein et al. (2008) in a meta-analysis of studies utilizing corn DDGS up to 40% of the diet reported a cubic trend on gain:feed with optimal efficiency at inclusion rates between 10 and 20%, while inclusion at 40% resulted in gain:feed similar to the control corn-based diets. In contrast to our study, Eun et al. (2009) reported no differences in gain:feed of cattle fed corn

DDGS as a replacement for barley grain at levels up to 18.3% (DM), although inclusion of corn DDGS numerically improved gain:feed. Discrepancies between trials may arise from the higher inclusion level of corn DDGS as the steers fed 20% corn DDGS in this study had a gain:feed (0.163 vs. 0.162, respectively) that was similar to those fed a diet with 18.3% corn DDGS (Eun et al. 2009).

The effects of corn DDGS on DMI and gain:feed is supported by the calculated NEg content of the diet (Table 2). The NEg content of corn DDGS rations increased ($P<0.01$) in a quadratic fashion ($y=1.274–0.0028x+0.0003x^2$, $R^2=0.96$, SEP 0.029) as the level of corn DDGS in the diet increased with a local minima at the 5.4% inclusion level. The NEg content of the control diet was estimated to be 1.27 Mcal kg^{-1} NEg while that of the 40% corn DDGS diet was estimated to be 1.58 Mcal kg^{-1} NEg, an improvement of 24%. Ham et al. (1994) reported a similar improvement (21%) in NEg content of the diet when corn DDGS replaced corn grain at 40% of the ration. This increase in NEg explains the reduction in DMI of the cattle fed 40% corn DDGS and the fact that gain was similar to the control cattle. Predicted NEg daily intake was similar for the control and 40% corn DDGS fed cattle (13.2 vs. 13.9 Mcal, respectively).

Ultrasound subcutaneous fat and USLD gain measurements were not affected by treatment ($P>0.05$) (Table 2). The lack of difference is likely a reflection of the similar NEg intakes amongst all diets (13.5±0.3 Mcal day^{-1}) (mean ± SD, DM) as well as the fact that the cattle were all taken to a common end point at slaughter.

No effects ($P>0.05$) of treatment were found on liver abscess scores (Table 3). Similar results were reported by Beliveau and McKinnon (2008) and Gibb et al. (2008). It has been proposed that adding DDGS to finishing diets would improve rumen pH due to its low starch and high fiber content (Galyean and Defoor, 2003; Klopfenstein et al. 2008). Beliveau and McKinnon (2009) however, reported that the addition of up to 21% wheat DDGS did not improve rumen pH relative to a barley-based control ration. These workers attributed the lack of sub-acute ruminal acidosis mitigation to low levels of physically effective fiber and reduced buffering capacity of DDGS. Furthermore, there was no difference in liver abscess scores between corn and wheat DDGS fed cattle (Table 3) and thus no evidence of a modulation influence on sub-acute ruminal acidosis as a result of the higher oil content of corn DDGS.

ii) Carcass Quality

There was no effect of DDGS (wheat or corn) inclusion level on hot carcass weight ($P>0.54$), estimated lean yield ($P>0.23$), grade fat ($P=0.18$) marbling scores ($P=0.09$ to 0.92) or *l. dorsi* area ($P=0.14$) (Table 3). However, dressing percentage linearly increased ($P<0.01$) with inclusion level of wheat DDGS ($y=58.00+0.0300x$, $R^2=0.47$, SEP 0.55). Beliveau and McKinnon (2008) also reported wheat DDGS at levels up to 23% in finishing rations had no effect on estimated lean yield or marbling scores. Gibb et al. (2008) observed a quadratic decrease in subcutaneous fat thickness as well as a trend for reduced lean meat yield, but no effect on dressing percentage as wheat DDGS inclusion increased (up to 60%) in finishing rations.

Dressing percentage increased ($P=0.01$) in a quadratic fashion ($y=58.00+0.1150x–0.0023x^2$, $R^2=0.50$, SEP 0.658) as corn DDGS inclusion level increased in the ration with a local maxima at 26% (DM). Similar to the results of the present study, Benson et al. (2005) also found a positive linear effect of corn DDGS (up to 35%, DM) on dressing

percentage. The higher dressing percentage when feeding corn DDGS is attributed to an increase in subcutaneous fat and poorer yield grades (Benson et al. 2005; Eun et al. 2009). In this study, wheat and corn DDGS at levels up to 40% (DM) had no effect ($P>0.05$) on estimated lean yield or grade fat although estimated lean yield (%) decreased and grade fat numerically increased numerically as DDGS (wheat and corn) increased (Table 3). In contrast, both Benson et al. (2005) and Eun et al. (2009) found yield grades to increase in response to greater inclusion levels of corn DDGS, again reflecting higher levels of subcutaneous carcass fat. The yields of sub-primal boneless boxed beef, trim and waste (fat and bone) were not affected by treatment ($P>0.05$) (Table 4), which is consistent with no differences in estimated lean yield and grade fat (Table 3).

e) Conclusions and Recommendations

The results of this study indicate that feeding wheat DDGS in finishing rations up to 40% of the ration causes an increase in DMI and reduced days on feed. In contrast, supplementing corn DDGS for barley in finishing rations at levels up to 40% results in a decrease in DMI and an improved gain:feed. Furthermore, feeding corn DDGS increased diet NEg. Inclusion of wheat or corn DDGS did not impact marbling scores, HCW, estimated lean yield, grade fat or sub-primal boneless boxed beef. However, dressing percentage increased as both wheat and corn DDGS inclusion increased. Results from this trial indicate that both wheat and corn DDGS can be supplemented for barley in finishing diets at levels up to 40% with no negative impact on performance, carcass quality or sub-primal boneless boxed beef yield. Cattle fed barley-based diets and supplemented with corn DDGS will exhibit improved gain:feed ratios due to decreased dry matter intake.

Table 2. Effects of feeding wheat or corn dried distillers grains with solubles (DDGS) at two inclusion levels on the performance of finishing cattle

	Dietary Treatment							P-value contrast			
		Wheat DDGS		Corn DDGS				Wheat DDGS		Corn DDGS	
	Control	20%	40%	20%	40%	SEM[z]	*P*-value	Linear	Quad	Linear	Quad
Start of trial weight (kg)	375	376	377	376	376	0.80	0.70				
End of trial weight (kg)	654	649	648	652	653	2.28	0.34				
Average daily gain (kg d^{-1})	1.62	1.63	1.73	1.66	1.68	0.03	0.13				
Dry matter intake (kg d^{-1})	10.4	10.2	10.9	10.2	8.8	0.11	0.01	0.02	0.01	0.01	0.01
Gain:Feed	0.156	0.159	0.158	0.163	0.192	0.002	0.01	0.65	0.52	0.01	0.01
NEg of diet (MCal kg^{-1})	1.27	1.30	1.26	1.32	1.58	0.02	0.01	0.41	0.11	0.01	0.01
Days on Feed	169	166	154	163	162	3.26	0.05	0.04	0.37	0.12	0.46
US backfat thickness (mm)[y]											
Start of test	2.2	2.2	2.6	2.2	2.0	0.24	0.51				
End of test	8.4	8.8	9.8	9.0	9.2	0.51	0.41				
Gain	6.2	6.8	7.4	7.0	7.0	0.46	0.47				
US longissimus dorsi area (cm^2)[x]											
Start of test	59.0	59.8	58.6	58.8	59.4	0.55	0.56				
End of Test	89.4	90.6	89.4	91.8	89.2	1.10	0.42				
Gain	31.0	30.6	30.8	33.6	29.8	1.39	0.39				

[z] SEM = pooled standard error of the mean

[y] Ultrasound measurements of subcutaneous fat thickness

[x] Ultrasound measurements of *longissimus dorsi* area

Table 3. Effects of feeding wheat or corn dried distiller grain with solubles (DDGS) at two inclusion levels on the carcass quality of finishing cattle

	Dietary Treatment							P-value contrast			
		Wheat DDGS		Corn DDGS				Wheat DDGS		Corn DDGS	
	Control	20%	40%	20%	40%	SEM[z]	*P*-value	Linear	Quad	Linear	Quad
Shrunk ship weight (kg)	639	632	634	633	636	2.5	0.42				
HCW (kg)	371.9	370.8	374.8	375.3	375.6	5.34	0.54				
Dressing percentage	58.0	58.6	59.2	59.4	59.0	0.27	0.01	<0.01	1.00	0.02	0.01
Grade fat (mm)[y]	7.8	8.2	9.0	8.2	9.0	0.41	0.18				
Estimated lean yield (%)[x]	61.2	60.6	59.8	60.6	60.0	0.45	0.23				
L. dorsi area (cm^2)	97.2	94.6	92.2	92.6	94.0	1.42	0.14				
Marbling score[w]											
Percentage with score 5	0.0	3.6	0.0	1.9	0.0	1.32	0.92				
Percentage with score 6	5.5	0.0	0.0	1.9	0.0	1.39	0.57				
Percentage with score 7	23.6	23.6	20.4	9.3	13.0	6.10	0.40				
Percentage with score 8	58.2	50.9	66.7	79.6	74.1	7.24	0.09				
Percentage with score 9	10.9	20.0	13.0	5.6	13.0	5.03	0.45				
Liver Abscess Score[v]											
Percentage with score 0	67.3	56.4	66.7	61.1	61.1	7.22	0.81				
Percentage with score 1	5.5	14.5	9.3	14.8	13.0	4.17	0.50				
Percentage with score 2	16.4	7.3	7.4	13.0	9.3	3.51	0.34				
Percentage with score 3	10.9	21.8	16.7	11.1	16.7	5.01	0.54				

[z] SEM = pooled standard error of the mean

[y] Grade fat is a measure of subcutaneous fat assessed perpendicular to the outside surface, within the fourth quarter of the rib-eye at the minimum point of thickness.

[x] Estimated lean yield = 63.65 + 1.05 (muscle score) - 0.76 (grade fat)

[w] Marbling score: 1 = very abundant, 5 = moderate, 6 = modest, 7 = small, 8 = slight, 9 = traces and 10 = devoid

[v] Liver abscess score: 0 = no abscesses, 1 = one small abscess (≤1.25 cm), 2 = two to four small to medium (≤2.54 cm) abscesses, 3 = one or more large abscesses or greater than four small to medium abscesses.

Table 4. Effects of feeding wheat DDGS or corn DDGS at two inclusion levels on the yield of SPBBB, trim and waste (fat and bone)[z]

	Dietary Treatment						
		Wheat DDGS		Corn DDGS			
	Control	20%	40%	20%	40%	SEM[y]	P-value
Left cold carcass weight (kg)	184.4	182.5	186.5	186.4	187.1	1.27	0.10
SPBBB, edible trim and waste (% of left cold carcass weight)							
SPBBB	61.13	60.49	59.61	60.51	60.15	0.466	0.27
Edible trim – 65% lean	1.42	1.29	1.36	1.42	1.47	0.130	0.89
Edible trim – 85% lean	7.97	7.57	7.66	7.70	7.36	0.424	0.38
Waste (bone and fat)	29.22	30.29	30.99	30.23	30.40	0.600	0.37

[z] Subsample of 100 steers; 20 from each treatment

[y] SEM = pooled standard error of the mean

Comparison of wheat or corn dried distillers grains with solubles on Rumen fermentation and digestibility characteristics of feedlot heifers

b) Introduction

The increased production of fuel based ethanol in North America has led to the feeding of distillers grains at high inclusion levels (20 to 40% of the ration) in feedlot rations. Dried distillers grains with solubles, the most common distillers byproduct, has a nutritional composition that is low in starch but concentrated three-fold in chemical composition (Spiehs et al. 2002). It has been speculated that since DDGS is essentially starch free, the incidence of SARA should be reduced relative to corn or barley grain fed cattle (Firkins et al. 1985; Larson et al. 1993). Furthermore, due to the lack of starch and subsequent high fiber content, VFA patterns and molar amounts are likely to change as a result of feeding DDGS (Ham et al. 1994). Research conducted by Ham et al. (1994) and Eun et al. (2009) did not find an effect of corn DDGS on mean ruminal pH or VFA concentration when fed at 40% of a corn-based finishing ration and up to 18.3% in a barley-based finishing ration, respectively. In contrast, Leupp et al. (2009) found total VFA and acetate decreased while propionate increased in a linear fashion, as corn DDGS inclusion increased up to 60% in corn rations.

Although limited research exists for wheat DDGS, Beliveau and McKinnon (2009) found propionate to decrease in a linear fashion with no effect on acetate levels as wheat DDGS increased (up to 21%) in barley-based rations. The authors, using *in-dwelling* rumen pH data loggers, also found a decreasing cubic effect on mean pH below the 5.8 and 5.5 thresholds in cattle fed wheat DDGS. Decreasing cubic effects were also found on pH area between 5.2 and 5.5 (pH x min) and time below 5.2 (min).

The digestibility of corn DDGS has been shown to be comparable to control corn-based 70% concentrate rations (Leupp et al. 2009). Leupp et al. (2009) also found that ruminal digestion of ADF and NDF in corn DDGS fed cattle tended to decline, however total tract digestion of both ADF and NDF were similar to cattle fed the control ration. In regards to environmental concerns over additional nitrogen and phosphorus intakes associated with feeding DDGS, Spiehs et al. (2009) found both nitrogen and phosphorus excretion to linearly

increase as corn was replaced by corn WDGS (up to 60%) in high concentrate rations. In terms of wheat DDGS digestibility, Gibb et al. (2008) found dry matter digestibility of cattle fed a 60% wheat DDGS diet to decline by 9.8% relative to a barley-based diet.

To date, no research has been conducted to compare rumen fermentation parameters and digestibility of wheat vs. corn DDGS based rations. Therefore, the objectives of this study were to compare cattle fed wheat-based DDGS to those fed corn-based DDGS in terms of rumen fermentation parameters, nutrient digestibility and to quantify the increased nitrogen and phosphorus excretion associated with feeding DDGS.

c) Methods

Five Hereford heifers (420 ± 6 kg, mean ± SD) were housed in 9 m^2 floor pens equipped with rubber floor mats and individual water bowls and feeders at the Livestock Research Barn (University of Saskatchewan). Upon arrival, all heifers received the same processing and vaccination protocol as the feedlot steers in Trial 1. After an acclimatization period (six weeks), all heifers were spayed and fitted with a soft, plastic rumen cannula (10 cm centre diameter; Bar Diamond, Parma, ID). All cattle were cared for in accordance with the guidelines of the Canadian Council on Animal Care (1993).

Each heifer was randomly assigned to one of five treatments using a 5 by 5 Latin square design. The trial was 170 days in length with 34 day periods. Each period consisted of a 12 day adaptation period, a 6 day (d 13-18) voluntary intake phase and a 16 day (d 19-34) collection period. During the collection period, 24 h eating behaviour was observed (d 19), 24 h rumen fluid sampling was performed (d 21), *in-dwelling* pH data was collected over 3 consecutive 23 h periods (d 25-27) and total fecal and urine collections were carried out during the remainder of the period for 5 consecutive days (d 29-34).

i) Treatments, Dietary Composition & Feeding

Heifers were fed a standard barley-based finishing ration (90% barley grain, 5% barley silage and 5% supplement, DM) before the trial commenced. The treatments were matched to the feedlot trial so that the control diet, on DM basis consisted of 88.7% rolled barley grain, 5.8% barley silage and 5.5% supplement (Table 1). For the other four treatments, wheat or corn DDGS were substituted for barley grain at 20 and 40% of the diet DM (Table 1). Rations were formulated to meet or exceed NRC (2000) requirements for CP, trace minerals and fat-soluble vitamins (Table 1). The Ca:P ratio was formulated to range from 1.5:1 to 2:1 with limestone added to the supplement as the DDGS content of the ration increased. Monensin sodium was fed at 27 mg kg^{-1} (DM basis) (Elanco Animal Health, Guelph, ON) in all diets.

The adaptation phase for all periods consisted of four equal steps in which the concentrate (barley and wheat DDGS or corn DDGS) was increased or decreased by 5 or 10%, at each step, depending on the target diet.

All animals were fed individually in two equal daily allotments at 0800 and 1600 h. Prior to the morning feeding, feed bunks were swept clean with orts removed, weighed and recorded. To determine *ad libitum* feed intake, heifers were fed so that 0.1 to 0.3 kg orts remained in the bunk the following morning. In order to calculate voluntary intake as a percentage of body weight, heifers were weighed on d 16 and d 17 prior to feeding. On d 22, a restricted intake period began prior to rumen insertion of *in-dwelling* pH probes, in which intake was restricted to 95% of *ad libitum* intake (DM basis). Feed was restricted to 95% of

ad libitum intake to ensure all feed was consumed during the period of pH measurement and the total collection period. Following pH measurement, there was a 2 d rest period (d 28 and d 29) before total collections ensued.

The wheat and corn DDGS used in this trial was the same as that used for the feedlot trial. Supplements were formulated and mixed in one batch per treatment to maintain consistency throughout the trial (Table 1). Barley grain (63.3±0.6 kg hL^{-1}, mean±SD) was purchased from commercial grain sources and dry rolled (RossKamp Champion, Waterloo, IA). The barley silage (AC Rosser) was grown at the University of Saskatchewan, harvested and ensiled. Silage samples were taken bi-weekly with the samples dried to determine dry matter content and used to adjust feeding amounts, if necessary. Load samples for DDGS (corn and wheat) and barley, batch samples for supplements and the bi-weekly silage samples were taken for chemical analysis.

Table 1. Composition and analysis of control and wheat and corn dried distillers grains with solubles (DDGS) rations

	Treatment				
		Wheat DDGS		Corn DDGS	
	Control	20%	40%	20%	40%
Diet Composition (% DM basis)					
Barley silage	5.8	5.8	5.8	5.8	5.8
Barley grain	88.7	68.7	48.7	68.6	48.6
Wheat DDGS	-	20.0	39.9	-	-
Corn DDGS	-	-	-	20.1	40.0
Supplement	5.5	5.5	5.6	5.5	5.5
Supplement composition (% DM basis)					
Barley	-	43.9	37.9	43.9	37.9
Canola meal	47.5	-	-	-	-
Canola oil	3.2	-	-	-	-
Urea	1.6	-	-	-	-
Limestone	21.8	30.4	36.6	30.4	36.6
Vitamin premix[z]	10.6	10.5	10.4	10.5	10.4
Ionophore premix[y]	8.2	8.1	8.1	8.1	8.1
Trace mineral salt[x]	7.1	7.1	7.0	7.1	7.0
Ration Analysis (% DM basis±SE)					
Organic Matter	95.5 ± 0.05	94.3 ± 0.11	94.5 ± 0.02	94.4 ± 0.08	93.6 ± 0.10
Crude protein	12.8 ± 0.04	18.1 ± 0.14	24.0 ± 0.18	15.4 ± 0.03	18.9 ± 0.12
Ether extract	1.6 ± 0.01	2.0 ± 0.02	2.7 ± 0.01	3.2 ± 0.01	5.1 ± 0.02
Acid detergent fiber	8.5 ± 0.05	10.8 ± 0.12	13.4 ± 0.12	9.3 ± 0.05	10.6 ± 0.08
Neutral detergent fiber	18.0 ± 0.06	24.3 ± 0.28	30.4 ± 0.29	23.8 ± 0.05	30.2 ± 0.22
Acid detergent insoluble nitrogen	0.04 ± 0.001	0.33 ± 0.004	0.62 ± 0.005	0.16 ± 0.001	0.28 ± 0.002
Neutral detergent insoluble nitrogen	0.21 ± 0.001	0.96 ± 0.014	1.71 ± 0.011	0.49 ± 0.002	0.79 ± 0.003
Calcium	0.54 ± 0.02	0.72 ± 0.02	0.99 ± 0.04	0.72 ± 0.01	0.92 ± 0.03
Phosphorus	0.40 ± 0.01	0.49 ± 0.01	0.65 ± 0.01	0.46 ± 0.01	0.58 ± 0.01

[z] University of Saskatchewan vitamin A & D supplement= 440,500 IU vitamin A, and 88,000 IU vitamin D_3 kg^{-1}

[y] University of Saskatchewan Feed Unit Ionophore Premix: Contains 96.77 % barley and 3.23 % Rumensin® Premix containing monensin (as monensin sodium) at 200 g kg^{-1} (Elanco, Guelph, ON) (DM basis)

[x] Trace mineral salt: 95 % NaCl, 12 000 ppm Zn, 10 000 ppm Mn, 4000 ppm Cu, 400 ppm I, 60 ppm Co, 30 ppm Se

ii) Rumen Fermentation

(1) *In-dwelling* Rumen pH Measurement

On d 25-27, all heifers were fitted with indwelling rumen pH probes and data loggers using the In-dwelling Continuous pH Measurement System (Dascor, Escondido, CA) as described by Penner et al. (2006). The *in-dwelling* pH measurements allowed for the continuous monitoring (30 sec measurement) of rumen pH in the ventral sac for 3 continuous 23 h periods. Every morning, between 0700 and 0800, the rumen pH probes were removed from the rumen, cleaned, recorded data downloaded and recalibrated (pH 4 and 7).

The pH data was then averaged for each minute and combined with the calibration data using SAS (Version 9.1; SAS Institute, Inc. Cary, N. C.) to summarize minimum pH, mean pH and maximum pH. The duration (min d^{-1}) and pH area (min d^{-1} x pH) under the curve were also calculated using thresholds (pH 5.8-5.5, pH 5.5-5.2 and pH <5.2) to summarize degrees of acidosis as mild, moderate and severe, respectively, according to Nocek (1997) and Penner et al. (2007).

(2) Rumen Fluid Collections

On d 21, rumen fluid was collected at two h intervals for 24 h, starting at 0800. Approximately, 250 mL of rumen contents were sampled from the rumen mat, ventral and dorsal caudal sacs and the reticulum to obtain a representative sample. The samples were combined, mixed and strained through four layers of cheesecloth. A Model 265A portable pH meter (Orion Research Inc., Beverly, MA) was used to measure the pH of the retained rumen fluid in duplicate immediately after straining. A representative portion of the collected fluid was stored and frozen (-20 °C) in 10 ml quantities for further analysis of VFAs (mixed with 2 ml of 25% (wt/vl) metaphosphoric acid solution), ammonia (mixed with 2 mL of 0.1 M sulphuric acid solution) and osmolality.

(3) Volatile Fatty Acid Analysis

Rumen fluid samples for VFA analysis were thawed overnight at 4°C before being centrifuged in a Beckman Centrifuge (Model JS-4.2SM; Palo Alto, CA) at 5,000 x g at 4°C for 15 minutes. Subsequently, 120 µL of the supernatant was transferred into duplicate 1.8 ml Eppendorf™ centrifuge tubes with a glass syringe and 0.45um syringe filter (Nalgene, Rochester, NY). Then 500 µL of 1 mM trimethyl acetic acid in acetonitrile was also added to the Eppendorf™ tubes to act as the internal standard along with 880 µL of acetonitrile. Samples were vortexed for 3 seconds before centrifuging at 14,000 x g for 5 minutes in a Microfuge® 18 Microcentrifuge (Beckman Coulter™, Palo Alto, CA). The sample supernatant was pipetted (1 mL) into an Agilent™ GC glass vial and capped. An Agilent 6890 Series Gas Chromatography System (Wilmington, DE) including an Agilent 7683 Series injector (5 µL) fitted with a Zebron ZB-FFAP High Performance GC Capillary Column (30.0 m × 320 µm × 0.25 µm, Phenomenex, Torrance, CA) was used to identify and quantify VFAs (acetate, propionate, isobutyrate, butyrate, isovalerate, and valerate) in every sample. A standard curve was made from purchased standards (Nu-Chek Prep, Inc. Elysian, MN) and used to quantify the concentration (mM) of the individual VFAs. Samples were prepared daily and placed on the autosampler twice daily. Samples that were prepared daily, but not initially placed on the autosampler were stored in the fridge to minimize volatization .

(4) Rumen Ammonia and Osmolality

Rumen ammonia-N and osmolality samples were thawed overnight at 4°C. Rumen ammonia-N samples were vortexed and centrifuged at 14,000 x g for 10 minutes at 4°C in an ICE MicroCL 17R Centrifuge (Thermo Electron Corporation, Waltham, MA). The phenol-hypochlorite procedure by Broderick and Kang (1980) was used to quantify the ammonia concentration once the rumen ammonia-N samples were centrifuged. Rumen osmolality was determined after centrifuging the thawed, non-acidified rumen fluid samples at 3,000 x g for 15 min using a Beckman Centrifuge (Model JS-4.2SM; Palo Alto, CA). A Vapro™ Vapor Pressure Osmometer (Model 5520; Wescor Inc., Logan, Utah) was used to determine the osmolality of the samples in duplicate. Standards (100, 290 and 1000 mmol kg^{-1}) were run initially and after every 24 samples to calibrate the osmometer.

iii) Feeding Behaviour

On d 19, a 24 h observation (0800-0800 h) was utilized to observe and record behaviour and physical activity using the methods of Maekawa et al. (2002b) and Yang and Beauchemin (2006c). Total time spent eating, ruminating and drinking as well as positions of standing, sitting and lying (resting) were recorded every 5 minutes and measured in min d^{-1}. It was assumed that animals that were observed exhibiting these behaviours continued to do so for the next five minutes (Meakawa et al. 2002b).

iv) Total Tract Collections

Total tract collections were performed for five days (d 30 to 35) of each period to determine nutrient digestibility of each treatment diet as well as the route and form of nitrogen and phosphorus excretion. Heifers were haltered and tethered, allowing enough space for lying, standing, drinking and eating. Indwelling bladder catheters (Bardex Foley Catheter, 75 mL capacity balloon; C. R. Bard Inc., Covington, GA) were inserted by a veterinarian one day prior to collections. Urine was collected via Nalgene tubing into plastic sealed vesicles containing 100-150 mL of HCl acid at 0800 on d 30. The concentrated HCl was used in order to reduce the pH to 2 so as to minimize volatization of ammonia (Stockdale and Rathbone 1992). The daily volume of collected urine was recorded at 0800 each day, mixed thoroughly, sub-sampled (20% of total daily output) and frozen at –20 °C. At the end of each period, the urine was thawed, mixed and sub-sampled for further analysis of total nitrogen and ammonia-N as well as phosphorus.

Total fecal output was collected from the floor. Designated monitoring times for fecal collection were continuous monitoring from 0530 to 1300, 2 h intervals from 1300 to 2300 and 3 to 3.5 h intervals from 2300 to 0530 with feces collected and stored in a covered plastic Rubbermaid™ container. The total daily fecal output was weighed daily from d 31 to d 35 at 0800 hours with representative 500 g samples collected in duplicate into two pre-weighed aluminum drying containers. Feces were then dried at 55 °C for at least 96 h. Fresh feces (1000 g) were sub-sampled on d 31 to d 35, stored at –20 °C and used for pH, P and extractable NH_3-N measurements.

v) Chemical Analysis

All silage and fecal samples were dried in a forced air oven at 55°C for 72 h. Dried forage samples were ground through a hammer mill fitted with a 1 mm screen (Christie Norris Laboratory Mill Size 8", Christie-Norris Ltd. Chelmsford, UK). Dried fecal and concentrate

samples were ground through a 1 mm screen using a Retsch ZM100 grinder (Haan, Germany). All silage, dried fecal and concentrate samples were analyzed in duplicate according to the Association of Official Analytical Chemists (2000) for DM by drying at 135 °C (AOAC method 930.15), CP (AOAC method 948.13), NDF treated with amylase and without the addition of sodium sulphite (AOAC method 2002.04), NDIN (using NDF residue and AOAC method 948.13) ADF (AOAC method 973.18) ADIN (using ADF residue and method AOAC method 948.13) and ether extract (AOAC method 920.39). Calcium and phosphorus were analyzed using the dry ashing procedure (AOAC methods 927.02 and 965.17, respectively). Calcium was determined using an atomic absorption spectrophotometer (Perkin-Elmer, Model 2380, CN, USA) while phosphorus was read at 410 nm on a spectrometer (Pharmacia, LKB-Ultraspec III, Stockholm, Sweden).

Urine was analyzed for total phosphorus using the molybdenum-phosphate method (AOAC method 964.06) and ammonia-N as described for the rumen fluid samples (Broderick and Kang, 1980). Wet fecal material was thawed at 4°C for 48 h (until thawed) before being thoroughly mixed and composited per period by heifer. Water soluble ammonia-N measurements on wet fecal samples were performed by placing duplicate 1.00 g of wet feces into 15 mL centrifuge tubes and covering with 10 mL of distilled, deionized water. Samples were then capped and vortexed to create a fecal suspension and placed at 4°C overnight. Approximately, 24 h later samples were centrifuged with a Beckman Centrifuge (Model JS-4.2SM; Palo Alto, CA) at 1500 x g for 15 min at 4°C. A 100 µL aliquot of the supernatant was then used to determine NH_3-N with the phenol-hypochlorite method (Broderick and Kang, 1980). Wet feces (5 g) were vortexed in distilled deionized water (25 mL) to form a suspension to determine fecal pH using a Fisher Scientific AR50 pH Meter (Accumet Research, Hudson, MA) (Fox et al. 2007). Methods outlined by Wolf et al. (2005) and Kleinman et al. (2005) were used to determine the water-soluble phosphorus content of wet fecal samples via the molybdenum-phosphate method (AOAC method 964.06). Wet fecal samples (1:50 g mL^{-1}), shaken for 1 h at 150 rpm and centrifuged at 1500 x g were placed at 4°C overnight before being analyzed for soluble phosphorus content.

vi) Statistical Analysis

Feeding behaviour, in-dwelling pH measurements, total tract nutrient digestibility and rumen fermentation parameters (pH, VFA, osmolality and ammonia-N) were analyzed as a Latin Square design using the mixed model procedure of SAS (Version 9.2; SAS Institute, Inc. Cary, N. C.) with the random effect of heifer and the fixed effects of treatment and period. The rumen fermentation data including the *in-dwelling* pH probes was analyzed using a repeated measures approach with the fixed effects of time (day) and treatment x time (day) included in the model. Denominator degrees of freedom were adjusted using the Satterwaithe adjustment. Results were analyzed using a protected F-test ($P \leq 0.05$) and trends were discussed at $P < 0.10$. Polynomial contrasts were used to determine the linear and quadratic effects of wheat or corn DDGS inclusion rate. Significant results ($P \leq 0.05$) were presented using slope (linear) or local maxima/minima (quadratic) for the best fit polynomial regression equation using Proc GLM.

d) Results

The composition of the diets used in this trial are given in Table 1. The rations were formulated with the same corn and wheat DDGS as used in Trial 1. The samples used in this trial were obtained as sub-samples when both the corn and wheat DDGS from Trial 1 were transferred into bins for the present study. The wheat DDGS utilized in this study averaged 6.8±0.04% N, 4.7±0.06% EE, 47.8±0.77% NDF (43.8% NDFn), 19.6±0.35% ADF, 21.8±0.10% ADIN (% N), 58.9±0.11% NDIN (% N), 0.11±0.01% Ca and 0.97±0.07% P (mean±SD, DM). While the corn DDGS averaged 4.8±0.03% N, 10.7±0.13% EE, 47.4±1.06% NDF (45.8% NDFn), 12.7±0.21% ADF, 13.7±0.06% ADIN (% N), 35.4±0.01% NDIN (% N), 0.05±0.03% Ca and 0.79±0.002% P (mean±SD, % DM).

Similar to the feedlot trial, the amount of crude protein in the ration increased as both corn and wheat DDGS was included at 20 and 40% of the ration. Crude protein content increased from 13.0% in the control to 18.1 and 24.0% in the 20 and 40% wheat DDGS rations and to 16.6 and 18.9% in the 20 and 40% corn DDGS rations. The diet ADF and NDF levels also increased as both corn and wheat DDGS inclusion increased. The NDF and ADF fractions increased from 18.3 and 8.6% for the control, respectively to 30.4 and 13.4% for the 40% wheat DDGS ration and to 30.2 and 10.6% for the 40% corn DDGS rations. The amount of ADIN and NDIN in the rations increased as both corn and wheat DDGS inclusions increased with the 40% wheat DDGS ration containing the highest amount of NDIN (0.99% DM basis) and ADIN (0.62% DM basis). Similar to Trial 1 the amount of phosphorus increased in the ration as DDGS inclusion level increased.

i) Rumen pH (spot and in-dwelling)

The overall rumen pH for both in-dwelling and spot sample methods of measurement was not different ($P>0.05$) between treatments (Table 2). Similarly no differences ($P>0.05$) in rumen pH parameters below critical pH cut-off values of 5.8, 5.5 or 5.2 were detected including duration (min d^{-1} or min kg OMI^{-1}) and pH area (pHxmin). While there were no treatment effects on rumen pH measurements, all diets resulted in rumen fermentation conditions that approached mild (pH<5.8) to moderate (pH<5.5) acidosis (Nocek 1997; Penner et al. 2007). For example the rumen pH of cattle fed 40% corn DDGS was on average 10 hours per day while those fed 40% wheat DDGS spent 6.8 hours below the pH cut-off values of 5.8. Time below pH 5.5 ranged from 4 to 2.4 h for the 40% corn and 40% wheat DDGS treatments, respectively (Table 2). Similar results were found with the other treatments where time spent in moderate acidosis (pH<5.5) was 2.3, 5.7 and 3.7 hours for the control, 20% wheat and 20% corn DDGS treatments, respectively.

The lack of benefits with respect to mitigating rumen pH when feeding DDGS is surprising, as DDGS have a considerably different nutrient make up than barley, which was the basis of the control ration. It is estimated that feed barley contains 50-55% starch (Hart et al. 2008) while wheat or corn DDGS contain 6.3 and 4.4% starch, respectively (Nuez-Ortin and Yu 2009). It is estimated that 75 to 85% of corn starch and 80 to 85% of barley starch is degraded in the rumen with 95% of the starch digested in the total tract for both cereal grains (Huntington 1997; Harmon 2004). Owens et al. (1998) reported that the inclusion of rapidly degradable starch in ruminant diets is the major precursor for the onset of acidosis. Therefore, when replacing barley with DDGS a low starch feedstuff, a higher and/or a more stable rumen pH would be expected. The lack of acidosis mitigation for wheat and corn DDGS treatments in the present study could be the result of a rapid disappearance of fraction

(A) starch (starch and free glucose) in distiller byproducts. Batajoo and Shaver (1998) found the A fraction represented 26.7% of starch in barley and 77.7% of starch in corn DDGS. However, it's possible that the high estimate of rapidly degradable starch in DDGS is overestimated due to the small particle size of DDGS (Batajoo and Shaver 1998). Furthermore, although the size of fraction A starch in DDGS is high, the actual starch content is low relative to barley (4.4 vs. 51.6%, respectively) (Hart et al. 2008; Nuez-Ortin and Yu 2009). Thus, it would be unlikely that this would induce acidosis although this may lower the ability of distiller grains to mitigate acidosis.

The inability of both wheat and corn DDGS to mitigate acidosis could also be the result of poor peNDF (peNDF) (Beliveau and McKinnon 2009). Beliveau and McKinnon (2009) found a peNDF value for wheat DDGS of less than 10%. Mertens (1997) hypothesized that the peNDF content should be at least 22% of the ration in order to stimulate rumination behaviour in dairy cattle. Kleinschmit et al. (2006) also monitored the particle size of corn DDGS and found the mean particle diameter of 0.81 mm to have an estimated peNDF value of 12.4%, similar to that of Beliveau and McKinnon (2009). The lack of peNDF in DDGS could in part, explain why ruminal acidosis was not improved with DDGS inclusion.

ii) Rumen fermentation (VFA, osmolality and NH_3-N)

There was a time effect (P=0.01) for all tested rumen fermentation parameters except valerate (P=0.20). The effect of time is well documented as rumen fermentation exhibits a diurnal pattern post-feeding (Nagaraja and Titgemeyer 2007). Propionate concentration tended (P=0.10) to decrease in a quadratic and linear fashion as wheat and corn DDGS inclusion increased, respectively. Beliveau and McKinnon (2009) found a linear decrease in propionate levels as wheat DDGS increased in the ration. A decrease in propionate production when feeding DDGS is not unexpected as high fiber feedstuffs promote acetate production (Sutton et al. 2003). Furthermore, concentrate feedstuffs such as barley promote propionate production, a gluconeogenic precursor (Sutton et al. 2003). Since DDGS are high in fiber and low in starch, the replacement of barley with DDGS in finishing diets would be expected to result in less propionate production and as a consequence result in less gluconeogenic precursors.

Butyrate increased in a quadratic fashion for wheat DDGS (y=10.8171+0.3551x-0.0078x^2, R^2=0.22, SEP=3.094) and in a linear fashion for corn DDGS (y=10.3661+0.1034x, R^2=0.28, SEP=2.694). Solving the equation for wheat DDGS gives a local maxima for butyrate concentration at a 22.9% DDGS inclusion rate. Kleinschmit et al. (2006) found that butyrate concentration increased in cattle fed 20% corn DDGS relative to a corn-soybean meal diet. Butyrate and acetate concentration increase with increasing amounts of forage in the ration (Sutton et al. 2003). Butyrate undergoes extensive metabolism in the rumen wall to ketone bodies (B-hydroxybutyrate or acetoacetate) and is used as an energy source by the rumen epithelium as only 10% of the butyrate produced in the rumen actually enters the portal drained viscera (Britton and Krehbiel 1993). Increased butyrate as observed in this study could supply the rumen epithelium with more energy, conserving propionate for gluconeogenesis. Thus even though propionate production decreased as both corn and wheat DDGS increased in the ration, a reduction in gain was not observed in Trial 1.

Valerate also increased in a linear fashion (y=1.3876+0.0320x, R^2=0.32, SEP=0.764) as wheat DDGS increased in the ration. Heldt et al. (1999) found the concentrations of valerate, isovalerate and isobutyrate to increase as total rumen degradable protein increased in the

ration. This would explain why valerate concentration increased as wheat DDGS inclusion increased but not when corn DDGS was fed as wheat DDGS has a higher amount of rumen degradable protein relative to corn DDGS (Boila and Ingalls 1994a).

Although, corn and wheat DDGS increased butyrate and tended to decrease propionate, the total VFA concentration did not differ among treatments (P=0.17). Therefore, it is also unlikely that rumen pH or osmolality would be impacted by dietary treatment, since the concentration of volatile fatty acids contributes to predisposition of rumen acidosis (Owens et al. 1998).

There was no effect of treatment on rumen osmolality (Table 3). Decreased osmolality levels would be expected when feeding a high fiber byproduct relative to barley or corn based diets since the high structural carbohydrate levels together with the lack of starch and subsequent lack of free glucose in the rumen would result in slower rumen degradation rates and lower the rate and extent of acid production in the rumen (Owens et al. 1998). Since there was no effect of treatment on rumen pH (Table 2), it could be assumed that osmolality levels would not be affected by treatment.

Rumen ammonia-N concentration increased in a linear fashion (y=7.00+0.15x, R^2=0.23, SEP=4.62) as wheat DDGS level increased (Table 3). Beliveau and McKinnon (2009) found a similar linear increase in rumen ammonia-N levels as wheat DDGS increased up to 21% of the ration. Both wheat (24.0%) and corn (18.9%) DDGS rations had a higher protein content relative to the control ration (12.8%). Inclusion of corn DDGS did not result in increased rumen ammonia-N levels (Table 3). This is likely a reflection of the higher content of rumen udegradable protein in corn DDGS. Boila and Ingalls (1994) found that 100% wheat DDGS had a lower level of rumen undegradable protein and a faster rumen degradation rate relative to blends of DDGS (70% wheat:30% corn and 75% wheat:25% corn). Corn DDGS also has a higher lipid content that could potentially increase the rumen undegradable protein content if the fat coats the feed particles. Although, limited research exists for estimating if ethanol fermentation changes the structure of these proteins, zein, the principle protein in corn grain is more resistant to ruminal degradation relative to gluten, the main protein in wheat (Messman et al. 1994). The high rumen undegradable protein content of both wheat and corn DDGS is due to processing conditions associated with ethanol production and subsequent drying of the distillers grains including dryer duration and temperature (Boila and Ingalls 1994; Spiehs et al. 2002).

iii) Feeding Behaviour

Supplementing 20 and 40% corn DDGS relative to the barley based control ration resulted in linear decreases (P=0.01) in overall rumination time (y=265.2-1.7x, R^2=0.40, SEP=36.79) and rumination while sitting (y=251.5-1.8x, R^2=0.40, SEP=39.20) (Table 4). Two factors contributing to the reduction in rumination time in heifers fed DDGS diets include a lower peNDF and a quadratic decrease in voluntary dry matter intake (Table 4) relative to those fed the control diet. Time spent ruminating is highly correlated to the amount of saliva produced and thus the amount of rumen buffers produced including that of bicarbonate and phosphate (Owens et al. 1998; Maekawa et al. 2002a). As a result, decreased rumination time can result in inadequate rumen buffering (Maekawa et al. 2002a).

This is supported by the fact that rumination per kg of OMI was not affected by treatment (P>0.05). It should be noted that in heifers fed the 40% corn DDGS diet, the visual appearance of a rumen mat during rumen fluid collections was either not present or not as

obvious as other treatments. The lack of the rumen mat indicates poor peNDF and thus poor buffering potential of the feed.

Unlike rumination time, no difference was found for chewing (P=0.13) (eating + ruminating) (Table 4). Although, both 40% wheat (13.5 min kg^{-1}) and corn (15.2 min kg^{-1}) DDGS treatments resulted in the higher numerical time spent eating per kg OMI relative to the control treatment (10.0 min kg^{-1}).

iv) Digestibility

No effect of wheat DDGS (P=0.09) was observed on the DMI of heifers during the metabolism trial (Table 4). However as observed in the feedlot trial with steers, DMI decreased (P=0.04) in a quadratic fashion (y=9.48+0.07x-0.002x^2, R^2=0.26, SEP=0.75) as corn DDGS level increased with a local maxima at a level of 16.75% inclusion rate (Table 4). Failure to see an effect of wheat DDGS on DMI may be attributed to the fact that the heifers were fed in individual stalls with no competition (Schwartzkopf-Genswein et al. 2003).

Although cattle fed wheat DDGS had similar intakes to those fed the control ration, the total tract digestibility of dry matter (y=80.91-0.12x, R^2=0.52, SEP=1.95) and organic matter (y=82.70-0.11x, R^2=0.48, SEP=1.97) decreased (P=0.01) in a linear fashion as cattle were fed increasing levels of wheat DDGS. The decrease in dry matter and organic matter digestibility between the control and 40% wheat DDGS fed heifers was 5.3 and 4.6%, respectively. The decrease is similar to the 9.8% decrease in dry matter digestibility found by Gibb et al. (2008) when comparing cattle fed 60% wheat DDGS to those fed a barley control ration.

Contrary, to cattle fed wheat DDGS, corn DDGS had no effect on total tract dry matter digestibility (P>0.05) (Table 5). Research performed with corn WDGS at levels up to 60% of the ration showed no difference between corn WDGS treatments and the control corn based rations (Vander Pol et al. 2008; Spiehs and Varel 2009). The difference in the dry matter digestibility between wheat and corn DDGS treatments could be a reflection of the higher intake of ADF or ADIN or the lower intake of fat in cattle fed wheat DDGS (Table 1).

With respect to crude fat, the inclusion of both wheat and corn DDGS increased (P=0.01) the digestibility of crude fat in a quadratic fashion (Table 5). The inclusion of wheat DDGS (y=71.920+0.7263x-0.0143x^2, R^2=0.35, SEP=5.494) had a local maxima of 25.4% while the inclusion of corn DDGS (y=71.920+1.258x-0.0196x^2, R^2=0.85, SEP=4.002) yielded a local maxima of 32.1%. The quadratic effect of both DDGS sources on crude fat digestibility is likely the result of intestinal fatty acid digestion decreasing, regardless of the degree of saturation, as the intake of fatty acids increased (Zinn et al. 1994; Plascencia et al. 2003). Vander Pol et al. (2008) found the total tract digestibility of crude fat in cattle fed a 40% corn WDGS ration to be higher than that of cattle fed a corn diet supplemented with corn oil to obtain a similar level of crude fat (81 vs. 71%, respectively). The increase in digestibility was speculated to have been the result of an increase in unsaturated fatty acids reaching the small intestine of cattle fed the corn WDGS relative to those fed the corn oil diet due to decreased biohydrogenation of the fat in WDGS (Vander Pol et al. 2008).

Therefore, the increase in the digestion of crude fat with wheat and corn DDGS diets is likely due to increased amounts of unsaturated fatty acids in the small intestine. The protection of the fatty acids in DDGS relative to corn or barley grain may result from the ethanol fermentation and drying process thereby protecting the fat in DDGS and rendering it resistant to biohydrogenation.

Wheat and corn DDGS differentially increased the digestibility of ADF differentially. The inclusion of wheat DDGS increased (P=0.03) the digestibility of ADF in a linear fashion (y=43.454+0.317x, R^2=0.34, SEP=7.657), while the inclusion of corn DDGS caused a quadratic increase (P=0.02) in the digestibility of ADF (y=42.268+1.473x-0.028x^2, R^2=0.57, SEP=7.48) with a local maxima at 26.3%. Similar to ADF digestibility, the digestibility of NDF increased in a linear fashion (P=0.01) as both wheat (y=52.565+0.303x, R^2=0.52, SEP=5.01) and corn (y=53.527+0.449x, R^2=0.80, SEP=3.99) DDGS increased in the diet. Preliminary research (DeHaan 1983), found the NDF digestibility of corn bran to be 87%. Ham et al. (1994) found the NDF digestibility of corn WDG, fed at 40% of a 90% concentrate ration to be higher than that of the a rolled corn (69.6 vs. 62.5%, respectively) ration. In contrast to these results, Leupp et al. (2009) fed increasing levels of corn DDGS (up to 60%, DM) in 70% concentrate diets (30% grass hay) and observed no effect on NDF digestibility and a trend for decreased ADF digestibility. Differences between studies are likely due to the amount and type of forage fed in the ration as grass hay would provide greater amounts of NDF and ADF, relative to the high concentrate diet fed in this trial. NDF intake (1.71 kg d^{-1}) and digestibility (53.4%) of the control ration in this trial was much lower than that presented by Leupp et al. (2009) (3.59 kg d^{-1} and 68%) but similar to the values for cattle fed 86% medium-flat rolled barley in the study by Beauchemin et al. (2001) (1.78 kg d^{-1} and 53.3%).

The increase in the digestibility of both ADF and NDF with both wheat and corn DDGS in this trial is likely the result of an increase in the rumen fermentability of the DDGS fiber. Due to the ethanol fermentation process, the fiber in DDGS is potentially more soluble and fermentable than the NDF in barley or corn grain. Also, Ham et al. (1994) speculated that a substantial amount of post-ruminal fiber digestion might occur in cattle fed distillers byproducts resulting in higher than expected energy values. The increased fiber digestibility of DDGS relative to cereal grains also helps explain why the NEg of rations containing DDGS are similar to barley control based rations in Trial 1 (Table 2) even though the energy value of fiber is normally lower than that of starch. Also, an increase in the ruminal digestion of DDGS may result from less starch in the ration and therefore a higher rumen pH, favourable to cellulolytic bacteria growth (Ørskov 1986; Martin et al. 1999). Since rumen pH was not affected by DDGS inclusion, it is more likely that an increase in the ADF and NDF digestibility resulted from increased fermentability of ADF and NDF via the ethanol process.

The digestibility of crude protein also increased in a differential response to inclusion of wheat and corn DDGS. While the inclusion of wheat DDGS did not affect apparent crude protein digestibility (P>0.05), the inclusion of corn DDGS resulted in a linear increase (P=0.01) (y=76.616+0.170x, R^2=0.75, SEP=1.77) in crude protein digestibility (Table 5). These results will be discussed in the nitrogen excretion section.

The digestibility of NDIN increased (P=0.01) in quadratic fashions as wheat (y=51.063+1.653x-0.024x^2, R^2=0.960, SEP=2.692) and corn (y=51.063+2.066x-0.029x^2, R^2=0.989, SEP=1.826) DDGS inclusion increased (Table 5). This resulted in local maximas for NDIN digestibility at 34.44 and 35.62% for wheat and corn DDGS, respectively. The NDIN content of feed equates to intermediate and slowly digestible protein fractions (B2 and B3). Both corn and wheat DDGS have high NDIN levels as the result of the ethanol fermentation and drying process. As the content of NDIN (Table 1) increased from 0.21% in the control ration DM to 1.71% and 0.79% for the 40% wheat and 40% corn DDGS rations, respectively, the digestibility of NDIN (Table 4.5) also increased from 51.1% to 78.9% and

87.0% for the control, 40% wheat and 40% corn DDGS diets, respectively. Therefore, NDIN serves as a highly digestible source of nitrogen in DDGS based rations.

The digestibility of ADIN also increased (P=0.01) in a quadratic fashion as both wheat (y=12.818+3.631x-0.063x^2, R^2=0.895, SEP=8.018) and corn (y=12.818+4.621x-0.078x^2, R^2=0.954, SEP=6.981) DDGS inclusions increased (Table 5). The solved local maximas for ADIN digestibility was 28.8 and 29.6% for wheat and corn DDGS levels, respectively. The increasing quadratic relationship for ADIN digestibility due to the inclusion of wheat and corn DDGS is somewhat surprising as ADIN, traditionally is a measure of protein heat damage (Licitra et al. 1996) and is deemed to be largely unavailable. The fact that digestibility of ADIN increased with increasing levels of corn or wheat DDGS suggests that these by-products had minimal heat damage of that ADIN levels do not reflect the amount of unavailable protein in DDGS. Previous research by Klopfenstein et al. (1996) and Ham et al. (1994) found no difference in the daily gain or protein efficiency of steers fed corn DDGS with different levels of ADIN (7.3 to 28.8%). Similar to these results, there was no effect of feeding the wheat DDGS with the high ADIN content (21.8% N) on ADG in Trial 1. It should be noted however that although the majority of the ADIN was digested (Table 5), the amino acid balance of the ADIN content is not known and therefore ADIN may not be metabolized efficiently (Van Soest and Mason 1991). The increase in the digestibility of ADIN and NDIN is most likely an increase in solubility due to the ethanol fermentation process.

Gross energy digestibility decreased (P=0.01) in a linear fashion for wheat DDGS (y=82.1548-0.1346x, R^2=0.57, SEP=1.102) but was not affected (P>0.05) by corn DDGS inclusion (Table 5). The decrease in gross energy digestibility was likely the result of increased intake of ash and fiber and lower intake of starch and crude fat relative to the control treatment (Table 1). Although, gross energy digestibility decreased as wheat DDGS increased, the digestible energy content of the feed was not affected by treatment (P>0.05). Furthermore, the digestible energy intake (Mcal d^{-1}) of heifers was not affected by treatment (P>0.05), supporting the conclusion in Trial 1 of steers eating to energy satiety.

The similar digestible energy content of the diets (Table 5) is interesting as the control ration differs greatly in nutrient composition relative to DDGS treatments. The starch in the control ration would supply the majority of the energy to the cattle whereas in the corn and wheat DDGS treatments, the lack of energy from starch is replaced with energy from increased fat, fiber and protein (Table 1) and increased fat and fiber digestibility (Table 5). Larson et al. (1993) fed WDGS to yearlings and found a calculated diet NEg of 1.48 Mcal kg^{-1} when fed at 40% of the ration relative to 1.21 Mcal kg^{-1} for the control fed cattle. Although, NDF digestion was not measured, the authors contributed 9% of the increased energy content of WDB to fat and speculated that residual ethanol and a reduction in subacute ruminal acidosis would account for additional energy gains relative to the control corn-based ration. Lodge et al. (1997) designed and fed a composite distillers grain similar in nutrient composition to WDGS and found a 10% improvement in gain:feed relative to the control corn ration (0.149 vs. 0.136, respectively) and a calculated NEg of 120% for the composite byproduct relative to the corn it replaced. When either the additional fat or protein from the composite was removed from the ration, similar decreases in gain:feed (2%) and energy (6%) were observed for both fat and protein removal relative to the composite byproduct fed cattle. Klopfenstein et al. (2008) concluded that an increase in energy from the protein in DDGS is likely the result of a higher rumen undegradable protein intake and thus a

protein content that avoids rumen fermentation losses. The findings from this trial of increased fiber digestibility with DDGS supports the hypothesis that DDGS, when fed in feedlot finishing rations are a high energy concentrate feedstuff.

v) Nitrogen and Protein Excretion

Fecal (y=45.471+1.115x, R^2=0.75, SEP=11.72) and urinary (y=99.317+1.995x, R^2=0.78, SEP=18.86) nitrogen excretion linearly increased (P=0.01) as wheat DDGS increased in the ration (Table 6). The inclusion of corn DDGS also increased (P=0.01) the excretion of urinary nitrogen in a linear fashion (y=119.20+2.996x, R^2=0.19, SEP=25.98). As a result, total nitrogen excretion increased in a linear fashion as both wheat (y=144.788+3.110x, R^2=0.84, SEP=24.13) and corn (y=171.272+2.308x, R^2=0.11, SEP=27.42) DDGS increased in the ration. Although, urine is the major route of excretion for nitrogen the linear increase in fecal nitrogen excretion for wheat DDGS supplementation signifies poor protein availability in the rumen and/or total tract of the animal. Even though ADIN digestibility increased in a linear fashion for wheat DDGS inclusion the increased intake of ADIN resulted in an additional 24 g of ADIN excreted per day for the 40% wheat DDGS fed cattle relative to 3 and 7 g of ADIN for cattle fed the control and 40% corn DDGS fed cattle, respectively.

Therefore the additional fecal nitrogen excretion is partly due to the higher ADIN intake of the 20 and 40% wheat DDGS (31 and 57 g d^{-1}, respectively) relative to the control (5 g d^{-1}) fed cattle, respectively.

Furthermore, the excretion of nitrogen is an environmental problem for feedlot operators if the nitrogen is volatile and thus lost to the atmosphere. Both wheat and corn DDGS tended to linearly increase (P=0.07) the amount of urinary ammonia. It is anticipated that the ammonia content of urine would immediately be volatized in a feedlot pen situation while urea would have the potential to be hydrolyzed into ammonia bacterial urease and be volatized (James et al. 1999). The inclusion of wheat DDGS tended (P=0.06) to linearly increase the amount of water-soluble ammonia in the feces. This finding could point to the potential for an increase in nitrogen run-off from manure or the susceptibility to volatize and create additional ammonia in the atmosphere.

The retention of nitrogen tended to increase (P=0.06) as a result of DDGS. Values for the control ration where 47.99 g d^{-1} and rose to 83.3 and 86.6 g d^{-1} for the 20% corn DDGS and 40% wheat DDGS fed cattle, respectively (Table 6). Spiehs and Varel (2009) also observed a numerical increase in nitrogen retention (59.4 to 72.6 g d^{-1}) in cattle fed increasing levels of corn WDGS (up to 60%). These values as well as those of the present study are relatively high. Spanghero and Kowalski (1997) estimated that 20 g of nitrogen per day were needed to put on 1 kg of body mass. Cattle fed 40% wheat DDGS and 20% corn DDGS diets should therefore be gaining upwards of 4 kg per day, which is not realistic. Sampling errors may have ensued, although the acidification of urine (pH<2) was checked every period. Furthermore, the ammonia content of urine was very minimal, signifying that there was adequate acidification (Table 6). Fecal nitrogen determination was performed on fecal samples that were dried at 55 °C (96 h) as well as with wet samples with an average nitrogen difference of 0.6%. Other sources of elevated nitrogen losses could be in the form of gaseous N_2 losses or nitrate and nitrite formation by rumen microbes (Spanghero and Kowalski 1997).

Phosphorus excretion increased (P=0.01) in a linear fashion as wheat (y=26.991+0.412x, R^2=0.77, SEP=4.10) and corn (y=26.991+0.412x, R^2=0.77, SEP=4.10) DDGS inclusion increased. Fecal phosphorus excretion increased (P=0.01) in a quadratic fashion as wheat DDGS increased in the ration (y=23.604+0.645x-0.0098x^2, R^2=0.41, SEP=6.06). While, urinary phosphorus excretion increased (P=0.01) in a linear fashion as both wheat (y=2.033+0.166x, R^2=0.42, SEP=3.52) and corn (y=2.033+0.166x, R^2=0.42, SEP=3.52) DDGS increased in the ration. The increase in phosphorus excretion would result in an increase in the phosphorus content of the manure. Potential agronomic problems in trying to manage the correct nitrogen:phosphorus ratio applied to the land could ensue. Furthermore, an increase in water soluble phosphorus can lead to leaching from stockpiled or applied manure, although no impact of wheat or corn DDGS was found on the water soluble phosphorus content of manure (Table 6).

Although phosphorus excretion increased as both wheat and corn DDGS were fed, there was also a trend (P=0.06) for wheat and corn DDGS to increase the amount of phosphorus retained. Widyaratne and Zijstra (2007) observed that pigs fed DDGS (wheat and corn) retained more phosphorus than pigs fed a control wheat ration. Calcium digestion also increased linearly (P=0.02) from 15.82% for the control to 23.95% for the 40% wheat DDGS treatment and to 30.86% for the corn DDGS treatments (data not shown). The increase in calcium absorption is likely the result of an increase in diet calcium content and phosphorus retention and the metabolism of the body in maintaining proper calcium:phosphorus ratios. The increase in phosphorus retention was likely the result of phosphorus being more soluble in DDGS and hence digestible (Widyaratne and Zijstra 2007) even though the control ration was formulated to meet their phosphorus requirements (NRC 2000).

There was also no effect of corn or wheat DDGS on fecal pH although numerically, the fecal pH of cattle fed the control ration was the lowest. The lack of an effect signifies that hind gut fermentation was not changed with the supplementation of a high fiber byproduct for the high starch barley grain.

Table 2. Rumen pH measurements of cattle fed wheat or corn DDGS at 20 and 40% inclusion levels

	Dietary Treatment						
		Wheat DDGS		Corn DDGS			
	Control	20%	40%	20%	40%	SEM[z]	*P*-value[y]
Mean Daily Rumen pH							
In-dwelling pH	6.00	5.87	5.98	5.95	5.87	0.11	0.81
Spot sample pH[x]	5.78	5.83	5.90	5.74	5.76	0.10	0.49
Rumen pH Parameter 5.8 or lower							
Mean pH	5.59	5.50	5.57	5.57	5.58	0.053	0.72
Total duration (min d^{-1})	434	576	407	517	604	155.0	0.85
Total duration (min kg OMI^{-1})	46.5	63.9	43.1	51.7	70.5	16.16	0.75
pH area (pH*min)	99.3	231.0	114.7	148.2	158.7	77.61	0.68
Rumen pH Parameter 5.5 or lower							
Mean pH	5.41	5.33	5.38	5.41	5.42	0.038	0.38
Total duration (min d^{-1})	138	342	146	224	237	127.8	0.73
Total duration (min kg OMI^{-1})	15.2	38.5	15.5	21.2	27.6	13.86	0.67
pH area (pH*min)	16.3	93.6	34.5	38.7	30.9	35.09	0.46
Rumen pH Parameter 5.2 or lower							
Total duration (min d^{-1})	5	152	46	13	40	57.7	0.28
Total duration (min kg OMI^{-1})	0.6	17.6	4.7	3.6	1.6	6.49	0.26
pH area (pH*min)	0.3	21.0	4.7	3.3	-	7.44	0.21

[z] SEM= Pooled standard error of the mean.

[y] *P*-values for Day and TreatmentxDay interaction are not shown as neither resulted in significant effects for any of the tested variables

[x] This variable was significant for time of collection (hour) (P=0.01)

Table 3. Effects of feeding wheat or corn DDGS at 20 and 40% inclusion levels on rumen fluid characteristics of cattle.

	Dietary Treatment							*P*–value Contrasts			
		Wheat DDGS		Corn DDGS				Wheat DDGS		Corn DDGS	
	Control	20%	40%	20%	40%	SEM[z]	*P*-value[y]	Linear	Quad	Linear	Quad
VFA (mmol 100 mol^{-1})											
Acetate	52.3	52.1	51.7	52.9	52.2	1.39	0.87				
Propionate	32.1	27.7	29.9	31.2	28.2	1.88	0.10	0.23	0.05	0.04	0.52
Butyrate	10.8	14.8	12.6	11.5	14.9	0.87	0.01	0.16	0.01	0.01	0.22
Isobutyrate	1.1	0.9	1.0	1.0	0.9	0.11	0.48				
Valerate	1.4	2.0	2.7	1.6	1.7	0.15	0.01	0.01	0.51	0.15	0.99
Isovalerate	2.1	2.5	2.1	1.8	2.0	0.20	0.23				
Total VFA *(mmol L^{-1})*	126.1	119.2	115.4	125.2	122.7	5.91	0.17				
A:P Ratio[x]	1.68	2.03	1.82	1.82	1.89	0.188	0.30				
Osmolality *(mOsm L^{-1})*	316.9	324.7	318.0	328.9	321.3	9.07	0.68				
NH_3-N *(mg dL^{-1})*	7.4	9.2	13.6	7.6	9.5	1.35	0.03	0.01	0.43	0.29	0.61

[z] SEM= Pooled standard error of the mean.

[y] *P*-value for time was significant (*P*=0.01) for all tested variables except valerate (*P*=0.20); the *P*-value for treatment x time was not significantly different for any variables

[x] A:P Ratio=Acetate (A, mmol) : Propionate (P, mmol) ratio

Table 4. Effect of graded levels of wheat or corn DDGS on the voluntary intake and eating behaviour of heifers fed a finishing ration

	Dietary Treatment							*P*–value Contrasts			
		Wheat DDGS		Corn DDGS				Wheat DDGS		Corn DDGS	
	Control	20%	40%	20%	40%	SEM[z]	*P*-value	Linear	Quad	Linear	Quad
Dry Matter Intake (kg day^{-1})	9.7	10.0	9.6	9.9	9.1	0.35	0.02	0.82	0.09	0.05	0.04
Dry Matter Intake (% BW)	1.90	1.88	1.87	1.87	1.76	0.067	0.08	0.55	0.89	0.02	0.35
Organic Matter Intake (kg day^{-1})	9.2	9.5	8.9	9.4	8.5	0.33	0.01	0.28	0.10	0.02	0.05
Organic Matter Intake (% BW)	1.81	1.77	1.74	1.77	1.65	0.06	0.04	0.15	0.96	0.01	0.39
Time (min day^{-1})											
Eating	96	99	121	91	129	12.6	0.18				
Eating *(min kg OMI^{-1})*	10.0	10.7	13.5	10.1	15.2	1.58	0.13				
Ruminating	268	255	235	225	199	17.0	0.01	0.08	0.82	0.01	0.58
Ruminating *(min kg OMI^{-1})*	28.0	27.4	26.4	24.2	23.4	2.15	0.19				
Chewing[y]	364	354	356	316	328	25.1	0.34				
Drinking	19	35	29	26	33	5.5	0.24				
Standing	514	514	508	555	569	35.6	0.55				
Ruminating	17	27	10	9	21	5.9	0.11				
Sitting	746	771	814	754	730	42.4	0.56				
Ruminating	251	228	225	216	178	17.6	0.04	0.22	0.57	0.01	0.93
Sitting or Resting[x]	682	695	698	669	693	37.9	0.95				

[z] SEM= Pooled standard error of the mean.

[y] Chewing = Eating + Ruminating

[x] No Ruminating

Table 5. The effect of wheat or corn DDGS at 20 and 40% inclusion levels in finishing diets on the apparent nutrient digestibility coefficients of heifers

	Dietary Treatment							*P*-value Contrasts			
		Wheat DDGS		Corn DDGS				Wheat DDGS		Corn DDGS	
Item (%)	Control	20%	40%	20%	40%	SEM[z]	*P*-value	Linear	Quad	Linear	Quad
Apparent nutrient digestibility coefficient (DM basis)											
Dry matter	80.42	78.55	76.15	81.55	79.49	0.864	0.01	0.01	0.79	0.46	0.16
Organic matter	82.18	80.36	78.42	83.33	81.40	0.824	0.01	0.01	0.95	0.49	0.14
Ether extract (crude fat)	71.51	80.73	78.10	88.22	90.84	2.146	0.01	0.04	0.03	0.01	0.02
Crude Protein	75.46	74.43	74.68	81.18	82.80	0.925	0.01	0.57	0.57	0.01	0.11
Neutral detergent fiber	53.39	58.97	64.50	65.79	70.54	1.650	0.01	0.01	0.99	0.01	0.09
Acid detergent fiber	43.46	51.70	55.20	61.75	56.50	3.700	0.04	0.03	0.58	0.02	0.02
Neutral detergent insoluble nitrogen	51.10	74.56	78.91	80.67	87.01	1.073	0.01	0.01	0.01	0.01	0.01
Acid detergent insoluble nitrogen	13.05	60.18	57.01	74.15	73.11	4.156	0.01	0.01	0.01	0.01	0.01
Gross energy	82.07	78.74	77.13	82.26	80.09	0.813	0.01	0.01	0.36	0.10	0.25
Digestible energy *(Mcal kg^{-1})*	3.87	3.43	3.45	3.61	3.65	0.162	0.39				
Digestible energy intake *(Mcal d^{-1})*	35.34	32.55	31.63	35.10	31.55	1.391	0.21				

[z]SEM= Pooled standard error of the mean.

Table 6. The effect of wheat or corn DDGS at 20 and 40% inclusion levels in finishing rations on the nitrogen (N) and phosphorus (P) balance and fecal pH in heifers.

	Dietary Treatment							*P*-value Contrasts			
		Wheat DDGS		Corn DDGS				Wheat DDGS		Corn DDGS	
	Control	20%	40%	20%	40%	SEM[=]	*P*-value	Linear	Quad	Linear	Quad
Fecal output, *(kg d^{-1})*	1.83	2.05	2.19	1.77	1.78	0.109	0.01	0.01	0.70	0.63	0.75
Urine output, *(kg d^{-1})*	7.71	9.38	12.66	8.28	10.57	1.491	0.03	0.01	0.49	0.06	0.50
Nitrogen (g d^{-1})											
Total N intake	193.31	275.37	352.77	256.90	261.62	12.391	0.01	0.01	0.80	0.01	0.02
Total N excreted	142.17	215.54	266.21	178.24	207.05	10.229	0.01	0.01	0.28	0.01	0.72
Feces	46.20	72.40	89.29	46.40	45.15	3.771	0.01	0.01	0.39	0.52	0.95
Water soluble ammonia-N	2.36	2.65	3.26	2.46	2.54	0.225	0.06	0.01	0.55	0.54	0.97
Urine	95.12	142.33	176.91	131.22	161.90	6.765	0.01	0.01	0.43	0.01	0.71
Urine ammonia-N	0.97	1.14	1.61	1.61	1.98	0.269	0.07	0.08	0.60	0.01	0.66
Apparent total N retained	47.99	61.73	86.57	83.33	54.57	12.074	0.06	0.02	0.67	0.65	0.03
Phosphorus (g d^{-1})											
Total P intake	36.76	46.62	59.51	45.01	49.84	1.960	0.01	0.01	0.24	0.01	0.22
Total P excreted	26.45	37.06	42.84	31.67	35.03	1.678	0.01	0.01	0.14	0.01	0.56
Feces	25.58	32.47	33.71	27.38	26.75	2.458	0.01	0.01	0.05	0.43	0.36
Water soluble P	1.30	1.59	1.24	1.59	1.48	0.151	0.11				
Urine	1.22	4.51	9.13	3.68	8.28	1.749	0.01	0.01	0.38	0.01	0.17
Apparent total P retained	9.57	9.85	16.66	14.16	14.81	1.863	0.06	0.01	0.17	0.06	0.39
Fecal pH	7.02	7.17	7.28	7.34	7.34	0.098	0.14				

[=]SEM= Pooled standard error of the mean.

e) Conclusions and Recommendations

The results of this study indicate that the inclusions of corn and wheat DDGS (up to 40%) in feedlot rations does not mitigate ruminal acidosis, however the inclusion of both byproducts strongly impacts nutrient digestibility. The inclusion of both wheat and corn DDGS resulted in quadratic and linear increases in butyrate concentration, respectively while feeding wheat DDGS also linearly increased rumen ammonia-N levels. The inclusion of corn DDGS decreased total rumination time and dry matter intake. With respect to the overall digestibility of the diet, the 40% wheat DDGS diet linearly decreased DM digestibility. Corn and wheat DDGS inclusion resulted in increased crude fat digestibility while the inclusion of corn DDGS also increased the digestibility of crude protein. The inclusion of both corn and wheat DDGS resulted in increased digestibility of ADF, NDF, ADIN and NDIN. Although, digestibility of gross energy decreased as wheat DDGS inclusion increased, digestible energy intake did not differ between treatments. In regards to nitrogen and phosphorus balance, wheat and corn DDGS treatments increased nitrogen and phosphorus excretion and tended to increase the retention of both nitrogen and phosphorus. The results from this trial indicate that both barley and corn DDGS can be supplemented for barley at levels up to 40% with no negative impact on ruminal acidosis or digestible energy intake, although, cattle fed corn and wheat DDGS will have increased nitrogen and phosphorus excretion.

f) Other

v) Paper published: McKinnon, J.J. and Walker A.M. 2008. Comparison of wheat-based dried distillers' grain with solubles to barley as an energy source for backgrounding cattle. Can. J. Anim. Sci. 88:721-724.

vi) Results from the first backgrounding study of this project were also presented in a poster at the Annual Meeting of the Canadian Society of Animal Science, Guelph, ON (August, 2008)

5) Use of wheat DDGS in the diets of broiler chickens

b) Introduction

Distiller's Dried Grains' with Solubles (DDGS) have been used in livestock feeding for some time but the rapid expansion of the ethanol industry has provided a much larger supply and opportunity. This opportunity is counterbalanced by increased competition between livestock and ethanol industries for the major substrate used in these industries, the cereal grains. This situation emphasizes the need to fully utilize the co-products of alcohol production in animal feeding. Although poultry are not considered the primary opportunity for feeding DDGS, there remains a significant opportunity if diets are formulated carefully using accurate measures of nutrient content and digestibility.

Wheat DDGS are a relatively new feed ingredient opportunity for the poultry industry and in comparison to extensive corn based DDGS research, there is relatively little research on their nutritional value. In addition, much of the research is relatively old and may not represent the co-products of modern alcohol production. Technology associated with grain fermentation and alcohol production has changed with the expansion of ethanol production, demonstrating a need to establish relevant digestible nutrient levels. A number of factors

such as selection of grains (genotype, cultivar), type of fermentation, and drying temperature and duration can influence the nutritional properties of wheat DDGS.

At the start of this research, wheat DDGS were being produced from Saskatchewan fuel ethanol plants (NorAmera BioEnergy Corporation and Husky Energy Inc.). The objective was to sample DDGS from these plants for testing while the research was in progress, the ethanol industry started to incorporate corn with wheat as a starting substrate. As a result, the original trial objectives could not be met. However, when possible wheat DDGS were obtained for testing as well as samples with corn incorporation. The subsequent start-up of Terra Grain Fuels permitted testing of additional wheat DDGS samples for digestibility and broiler production research. The overall objective of this research was to define the digestibility of key nutrients in wheat DDGS for poultry and establish the feeding value in broiler chickens. Three experiments were completed to test the Apparent Metabolizable Energy (AMEn – two trials) and digestible amino acid content (one trial) of DDGS samples and one experiment was completed that incorporated up to 25% wheat DDGS in broiler diets.

c) Methods

i) Apparent Metabolizable Energy

Two experiments were completed to determine the AME of DDGS samples. The procedures were identical except for the basal diet used in the two experiments. One-day-old male broiler chicks (Ross x Ross 308) were placed in battery cages with dimensions of 50 cm in width, 85 cm in length and 25 cm in height. The total number of chicks used was 252 and 108 for Experiments 1 and 2, respectively. Chicks were fed a commercial starter diet until 14 days of age. At 14 days of age, birds were weighed and randomly assigned to six replications (cages) per treatment with each replication having six birds. From day 14 to 21, treatments included a basal reference diet and diets where 40% of the basal diet was replaced by test ingredients. The composition of basal and test diets used in the two experiments is shown in Table 1. The source and chemical characteristics of the test samples in Experiments 1 and 2 are shown in Table 2. The diets, in mash form, and water were provided on an *ad libitum* basis throughout the experiment. Birds were kept under 23L:1D lighting program (30 to 40 lux) and a standard brooding temperature curve was used. Body weight was determined on a cage basis at 14 and 21 days of age and feed intake was recorded for the 14 to 21 day experimental period. Mortality was recorded daily.

Faeces were collected during the last 2 days of the experiment (i.e. day 20 and 21), immediately frozen (< -20°C) and then subsequently oven-dried at 55°C and ground (1 mm screen) for chemical analysis. Analyses included moisture (AOAC, 1990), gross energy (AOAC, 1990), acid insoluble ash (Vogtmann et al., 1975) and nitrogen (AOAC, 1995) in order to determine diet AMEn. Calculations to determine AMEn were performed according to the procedure of Bartov (1995).

Statistical analysis was conducted as a one way ANOVA using the Proc GLM procedure of SAS. Means separation was carried out using the Duncan Multiple Range Test. Differences were considered significant when $P < 0.05$ and all differences were noted when $P < 0.10$.

ii) Digestible Amino Acid Content

The digestibility of amino acids in two samples of wheat DDGS (AMEn Experiment 2) was estimated using the standardized ileal amino acid digestibility assay. The standardized

ileal amino acid digestibility is a recently developed method, which measures the endogenous losses in growing birds in a relatively physiologically normal condition. This technique uses either a nitrogen free or hydrolyzed casein treatment to predict endogenous losses. Birds fed with hydrolyzed casein may have higher amount of endogenous losses compared to nitrogen free diet fed birds. This is because hydrolyzed casein induces the synthesis and secretion of endogenous amino acid. Hence, hydrolyzed casein may produce more accurate and precise basal endogenous loss value compared to nitrogen free diet due to birds under the more physiologically normal gastrointestinal tract condition. As a result of this logic, hydrolyzed casein (N-Z Case, Sigma Chemical Co., St. Louis, MO), as the only source of protein in the diet, was used to measure endogenous losses in this research.

Three diets were formulated to contain approximately 18% protein with all protein derived from either the test ingredients or hydrolyzed casein (Table 3). After mixing, diets were cold pelleted (Size of hole of pelleter: 4.50 mm in diameter (22-3/16), Hobart Corporation, Germany) to improve diet palatability. Water was added to the diet to improve the pelleting process and diets were immediately oven-dried at 55°C. Celite (insoluble ash) was used as an indigestible marker at 1.5% of diet.

Day-old male Ross x Ross 308 chicks were placed in battery cages (same as in AMEn trial) and fed a commercial diet until 17 days of age. At 17 days of age, the broilers were randomly assigned to replication units (6 birds per cage) and fed experimental diets with 6 replications per treatment. Birds were weighed on a cage basis at 17 and 21 days of age and feed intake records were kept for that time period. Mortality was recorded daily.

On day 21, the birds will be killed by cervical dislocation and the contents of the distal ileum (last half of the ileum minus the last 2 cm) were collected and frozen (<-20°C) for analysis. Digesta collected from birds in the same replicate were pooled. After freeze-drying, the digesta samples were ground with a mortar and pestle, and mixed thoroughly before analysis in duplicate for dry matter (AOAC, 1990), nitrogen (AOAC, 1995), amino acid content (AOAC, 1994) and acid insoluble ash (Vogtmann et al., 1975).

For digestibility of amino acid in a diet:

$ADC_{amino\ acid}$ (%) = 1 – [(% AIA diet)/ % AIA digesta x (% nutrient in digesta)/% nutrient in diet]

Where $ADC_{amino\ acid}$ = Apparent digestibility coefficient of amino acid in diet

Standardized digestibility coefficient (%) = $ADC_{amino\ acid}$(%) + [(basal endogenous amino acid losses (g/kg of dry matter)/(amino acid content in feed (g/kg of dry matter) x 100] (Lemme et al. 2004)

iii) Broiler Productivity

Dietary treatments included two samples of wheat DDGS obtained from Terra Grain on April 28 and June 23, 2009. These samples were included in broiler starter, grower and finisher diets and fed to broilers in a 35 day trial. Six levels of wheat DDGS inclusion were tested with 0, 2.5, 5.0, 7.5, 10.0 and 12.5% in the starter diet and 0, 5, 10, 15, 20 and 25% in the grower and finisher diets (see Tables 4 to 6). Diets were formulated for extremes of inclusion limits and then intermediate diets were calculated. The diets were formulated on

digestible energy and amino acid basis to provide recommended values for the Ross x Ross 308 genotype used in this research.

Chicks (Ross x Ross 308 females) were hatched at a commercial hatchery (Lilydale Foods, Wynyard, SK) and transported to the Poultry Centre on day of hatch. Chicks were then randomly placed into experimental pens. A total of 3,312 chicks were used with 69 per pen. The resulting market housing density approximated 30 kg/m^2. Each pen measured 2.3 x 2.0 m providing 4.6m^2 of floor space. Four rooms were used in the experiment and each room contained 12 pens; one replication of each experimental diet was place in each room thereby providing 4 replications per treatment.

Pens were bedded with fresh wheat straw to a depth of approximately 7.5 to 10 cm. Supplemental heat was provided by hot water pipes and temperature was controlled thermostatically and gradually reduced from 34°C at day 0 to 22° at day 35. Feed was fed ad libitum in 1 tube feeder per pen (0 to 24 days – 110 cm circumference; 24 days to market – 137.5 cm circumference). Birds were fed starter to 10 days, grower to 25 days and finisher to the end of trial. Water was also provided ad libitum using Lubing 4087 nipple drinkers (6 nipples per pen). All birds were given 23L:1D until 7 d of age and then 18L:6D until market age. Light intensity was 20 lux until 7 days of age and 10 lux thereafter. Lighting was provided with incandescent bulbs.

Chicks were weighed on a pen basis at 0, 10, 25 and 35 days of age and feed intake was measured for comparable time periods. Resulting information was used to calculate feed to gain ratio and feed to gain ratio corrected for mortality. The latter calculation added the weight of dead birds within a period to the final pen weight. Birds were monitored on at least a twice daily basis. Dead birds and those culled (sick or unable to move) were recorded, weighed and submitted to the Prairie Diagnostics Services (Western College of Veterinary Medicine, University of Saskatchewan) for necropsy. The wetness of litter within pens was assessed at 15 AND 22 days of age using a subjective scoring system (1 = no packing or fecal buildup, 2 = small non-continuous area of packing, 3 – 75% or more of area covered by fecal buildup, wet). Scoring was done in two pre-determined sites within the pen, under the waterers and away the impact of the waterers.

Statistical analysis utilized a 2 (sample of DDGS) x 6 (level of DDGS inclusion) factorial arrangement within a randomized complete block design with rooms serving as the block. Analysis was completed using the Proc GLM procedure of SAS (Version 9.2). Mortality data were (log+1) transformed prior to analysis. Means separation was carried out using the Duncan Multiple Range Test. Differences were considered significant when $P < 0.05$ and all differences were noted when $P < 0.10$.

d) Results

The AMEn values on a dry matter and 90% dry matter basis are shown in Table 7. Values within and between plants varied in the first experiment and this is likely due to the variable nature of the starting material, and the nature and effectiveness of the ethanol process. Energy is primarily derived from carbohydrate (in the case of chickens primarily starch), fat (ether extract) and protein. The chemical analysis of the samples shown in Table 2 shows a range in starch content of 1.8 to 9.5%, in fat content of 3.61 to 10.3% and of protein content of 33.7 to 43.9%. This variation undoubtedly impacts the AMEn values and its variation. Although not well defined, the starting material used in the ethanol manufacturing process varied in terms of the nature of the wheat used and in some cases involved the use of

wheat/corn mixtures. This is particularly obvious in the levels of protein and fat in the DDGS samples. The samples examined in Experiment 2 tended to be more consistent and this reflects the use of the same wheat cultivar as starting material.

The apparent ileal digestibility values for the two Terra Grain samples are shown in Table 8. The two samples demonstrated little variation between samples and high amino acid digestibility. The good digestibility of the samples was not expected as the heating associated with DDGS is known to negatively affect digestibility of amino acids. As a result key analysis ere repeated but the results did not change in a meaningful way. We have also done amino acid digestibility on another Terra Grain sample and this is also included in Table 8 for comparison. Lower, but still reasonable values were obtained in this sample. Amino acid digestibility in DDGS samples is well known to vary because of variable heat application during processing so variability in results is not unexpected. The high values obtained in this research should be added to other research on wheat DDGS digestibility to put them into perspective. This is done in the next section.

The effects of feeding graded levels of wheat DDGS on broiler productivity are shown in Table 9. There were no interactions between DDGS sample and level of inclusion and therefore only main effects are described. The DDGS samples used were of high quality and comparable, as judged by chemical analysis and digestibility trials. Therefore, it was not unexpected to see minor effects of sample on broiler performance. The "June" sample resulted in a heavier boy weight at 25 days of age and superior gain to feed ratio from 0 to 35 days of age. Birds fed the "April" sample ate more feed from 25 to 35 days of age. Even significant effects were small and likely of little practical significance. There was no effect of DDGS sample on mortality corrected feed efficiency (gain to feed) indicating that nutritional value of the meal samples was very similar and that the significant effect on gain to feed ratio noted above was determined by minor and non-significant differences in mortality (7.55 vs 6.88% for April and June samples, respectively). Diets were formulated to be of equal nutritional value and therefore no effects of level of DDGS inclusion on broiler performance were expected. For the most part, this was the case with level of inclusion not affecting growth or feed intake parameters. However feed efficiency (gain to feed ratio with and without mortality correction) improved with increasing level of DDGS inclusion for 10 to 25 and o to 35 day time periods. The reason for this improvement is not clear. Possible explanations are an underestimation of the digestibility (AMEn, amino acids) of the DDGS samples or an increase net energy with increasing DDGS inclusion due to increasing supplemental fat levels. Because of the very high digestibility of amino acid levels found in our research, we chose to use more moderate digestibility coefficients to formulate broiler diets, values that approximated other research that we have done with Terra Grain wheat DDGS samples (Table 8). If the digestibility coefficients were in fact as high as our results indicated for the samples used in the production trial, this could at least partially account for this effect. Mortality was affected by level of DDGS inclusion but this effect is likely by chance since there is no clear relationship between level of inclusion and mortality incidence. Categorization of mortality did not show important effects due to DDGS sample or level of inclusion.

Cereal grains are recognized as not having good amino acid balance for animal feeding, being particularly low in the first of second limiting amino acid lysine. Therefore, the amino acid balance of wheat DDGS reflects the poor balance of the initial wheat sample, only being slightly improved due to protein derived from yeast during the fermentation step of ethanol

production. Because of the poorer balance in comparison to soybean meal, increasing levels of dietary DDGS results in the use of more synthetic amino acids (particularly L-Lysine) and an increase in dietary protein to compensate for other essential amino acids that are not economically available for addition to animal diets. It is well known that increased protein intake results in increased water intake to facilitate elimination of the uric acid which is the urinary excretion product of protein catabolism. The result of increased water intake is wetter litter that can affect both broiler productivity (e.g. high ammonia) and welfare (e.g. foot pad dermatitis). We assessed litter quality on two occasions and two locations in this research and found that litter quality worsened with increasing DDGS inclusion in the diet (Table 11). Although there was no important biological effect in this trial, it may be an issue in barns where ventilation is compromised or during cold weather when ventilation rates are reduced.

Table 1. Composition of basal and test diets in AMEn Experiments 1 and 2

	Experiment 1		Experiment 2	
Ingredients (%)	Basal diet	Test diet	Basal diet	Test diet
Corn	91.29	52.75	60.30	34.80
Soybean meal			31.09	17.88
Canola oil	3.46	2.00	3.00	1.73
Di-calcium phosphate	1.81	1.81	1.80	1.80
Indigestible marker (Celite)	1.50	1.50	1.50	1.50
Limestone	0.84	0.84	1.15	1.15
Vitamin/mineral premix[1]	0.50	0.50	0.50	0.50
Salt	0.40	0.40	0.49	0.49
Choline chloride	0.10	0.10	0.10	0.10
Avizyme 1302[2]	0.10	0.10	0.025	0.025
Endofeed[3]			0.025	0.025
Test ingredient (DDGS)		40.00		40.00
Calculated nutrients				
Crude protein (CP)	7.7		20.4	
Calcium	0.74		1.00	
Available phosphorus	0.42		0.49	
AMEn	3,380		3,058	
Methionine	0.34		0.31	
Lysine	0.24		1.07	

[1]Supplied per kilogram of diet: vitamin A (retinyl acetate + retinyl palmitate), 11000 IU; vitamin D, 2200 IU; vitamin E (dl-α-topheryl acetate), 300 IU; menadione, 2.0 mg; thiamine, 1.5 mg; riboflavin, 6.0 mg; niacin, 60 mg; pyridoxine, 4 mg; vitamin B_{12}, 0.02 mg; pantothenic acid, 10.0 mg; folic acid, 0.6 mg; biotin, 0.15 mg; iron, 80 mg; zinc, 80 mg; manganese, 80 mg; copper, 10 mg; iodine, 0.8 mg; selenium, 0.3 mg; and $CaCO_3$, 500 mg.

[2] Avizyme 1302 – Danisco Animal Nutrition, Box 777, Marlborough, Wiltshire, SN8 1XN United Kingdom (5000 U/g endo-1,4-beta-xylanase EC 3.2.1.8, 1600 U/g subtililsin (protease) EC 3.4.21.62)

[3] Endofeed – GNC Bioferm Inc., PO Box 6, Bradwell, SK, Canada S0K 0P0. Principal enzyme components are β-glucanase and endo-xylanase.

Table 2. Source and chemical analysis[1] of DDGS samples

DDGS Sample Source	H_2O[2] (%)	CP (%)	EE (%)	ADF (%)	NDF (%)	NDIN (%N)	Starch (%)
Experiment 1 (CTR 0720)							
Wheat – NorAmera July 10th	11.0	38.4	6.8	14.3	48.0	3.32	6.0
Wheat – NorAmera Aug 21st	5.4	33.8	3.7	13.5	44.5	2.82	9.5
Wheat – NorAmera Sept 22nd	7.4	39.1	4.1	15.7	48.3	3.50	3.3
Wheat – Husky May 30th	9.4	37.9	4.8	11.3	52.7	3.57	1.8
Wheat/corn – Husky July 27th	11.2	34.1	10.3	13.2	55.9	3.24	5.2
Wheat/corn – Husky Sept 14th	10.6	33.7	8.2	11.7	56.1	3.29	3.7
Experiment 2 (CTR0923)							
Wheat – Terra Grain April 28th	5.2	43.89	3.61	13.6	43.0	3.05	3.8
Wheat – Terra Grain June 23rd	5.4	40.20	3.61	10.6	41.9	2.92	4.2

[1] Dry matter basis

[2] H_2O – water; CP – crude protein; EE – ether extract; ADF – acid detergent fibre; NDF – neutral detergent fibre; NDIN – neutral detergent insoluble nitrogen.

Table 3. Diet composition for standardized ileal amino acid digestibility assay[1]

Ingredient (%)	Hydrolyzed casein	Terra Grain April 28th	Terra Grain June 23rd
Hydrolyzed casein	20.00		
Wheat DDGS (CP 37.43%)		48.09	
Wheat DDGS (CP 38.05%)			47.31
Corn oil	2.00	2.00	2.00
Dextrose	66.23	43.58	44.37
Solka floc	3.50		
Salt	0.40	0.40	0.40
Di-calcium phosphate	2.38	2.27	2.27
Limestone	0.98	1.21	1.21
$NaHCO_3$	0.26		
$KHCO_3$	1.02		
MgO	0.77		
Celite	1.50	1.50	1.50
Vitamin/mineral premix[2]	0.50	0.50	0.50
Choline chloride	0.10	0.10	0.10
Avizyme 1302[3]	0.025	0.025	0.025
Endofeed[4]	0.025	0.025	0.025
Maxibond[5]	0.300	0.300	0.300

[1] Ravindran et al. 2004; Golian et al. 2008.

[2] Supplied per kilogram of diet: vitamin A (retinyl acetate + retinyl palmitate), 11000 IU; vitamin D, 2200 IU; vitamin E (dl-α-topheryl acetate), 300 IU; menadione, 2.0 mg; thiamine, 1.5 mg; riboflavin, 6.0 mg; niacin, 60 mg; pyridoxine, 4 mg; vitamin B_{12}, 0.02 mg; pantothenic acid, 10.0 mg; folic acid, 0.6 mg; biotin, 0.15 mg; iron, 80 mg; zinc, 80 mg; manganese, 80 mg; copper, 10 mg; iodine, 0.8 mg; selenium, 0.3 mg; and $CaCO_3$, 500 mg.

[3] Avizyme 1302 – Danisco Animal Nutrition, Box 777, Marlborough, Wiltshire, SN8 1XN United Kingdom (5000 U/g endo-1,4-beta-xylanase EC 3.2.1.8, 1600 U/g subtililsin (protease) EC 3.4.21.62)

[4] Endofeed – GNC Bioferm Inc., PO Box 6, Bradwell, SK, Canada S0K 0P0. Principal enzyme components are β-glucanase and endo-xylanase.

[5] Maxibond - AG Research Inc., Joliet, IL, USA, 60435.

Table 4. Broiler starter diet composition

	% wheat DDGS inclusion (starter/grower/finisher)					
Ingredient (%)	0/0/0	2.5/5/5	5/10/10	7.5/15/15	10/20/20	12.5/25/25
Wheat	56.01	54.39	52.77	51.15	49.53	47.91
Soybean meal	34.53	33.58	32.62	31.67	30.71	29.76
Wheat DDGS	0.00	2.50	5.00	7.50	10.00	12.50
Canola oil	4.03	4.12	4.20	4.29	4.37	4.46
Limestone	2.040	2.058	2.076	2.094	2.112	2.130
Di-calcium phosphorus	1.490	1.452	1.414	1.376	1.338	1.300
Sodium chloride	0.310	0.300	0.290	0.280	0.270	0.260
DL-Methionine	0.300	0.292	0.284	0.276	0.268	0.260
L-Lysine HCl	0.160	0.184	0.208	0.232	0.256	0.280
L-Threonine	0.110	0.110	0.110	0.110	0.110	0.110
Vitamin-mineral premix[1]	0.500	0.500	0.500	0.500	0.500	0.500
Choline chloride	0.100	0.100	0.100	0.100	0.100	0.100
Avizyme 1302[2]	0.050	0.050	0.050	0.050	0.050	0.050
Biocox[3]	0.050	0.050	0.050	0.050	0.050	0.050
Stafac 44[4]	0.025	0.025	0.025	0.025	0.025	0.025
Probond[5]	0.300	0.300	0.300	0.300	0.300	0.300
Calculated analysis (%)						
AME (kcal/kg)	3,000					3,000
Crude protein	24.16					25.79
Crude fat	5.46					6.11
Calcium	1.10					1.10
Available phosphorus	0.50					0.50
Total phosphorus	0.73					0.74
Sodium	0.18					0.18
Linoleic acid	1.51					1.70

Total/digestible Arg	1.53/1.40	1.57/1.39
Total/digestible Ile	0.97/0.88	0.99/0.86
Total/digestible Leu	1.72/1.53	1.77/1.55
Total/digestible Lys	1.41/1.27	1.45/1.27
Total/digestible Met	0.63/.60	0.63/0.59
Total/digestible Met&Cys	1.03/0.94	1.06/0.94
Total/digestible Thr	0.95/0.83	1.00/0.83
Total/digestible Val	1.07/0.95	1.12/0.95

[1] Broiler vitamin and mineral premix (NP# 82059025) – DSM Nutritional Products, 395 Waydom Drive, Ayr, On, Canada N0B 1E0. Amount per kg of feed - vitamin A – 11000 IU; vitamin D – 2200 IU; vitamin E – 30 IU; menadione – 2 mg; thiamine – 1.5 mg; riboflavin – 6 mg; pyridoxine – 4 mg; vitamin B_{12} – 0.02 mg; niacin – 60 mg; pantothenic acid – 10 mg; folic acid – 0.6 mg; biotin – 0.15 mg; copper (copper sulphate 25%) – 10 mg; Iron (ferrous sulphate 30%) – 80 mg; Manganese (manganous oxide 60%) – 80 mg; Iodine (calcium iodate 62%) – 0.8 mg; Zinc (zinc oxide 72%) – 80 mg; Selenium 0.3 mg; calcium carbonate – 500 mg; ethoxyquin – 125 mg; wheat middlings – 3.8 g.

[2] Avizyme 1302 – Danisco Animal Nutrition, Box 777, Marlborough, Wiltshire, SN8 1XN United Kingdom (5000 U/g endo-1,4-beta-xylanase EC 3.2.1.8, 1600 U/g subtililsin (protease) EC 3.4.21.62)

[3] Biocox – Alpharma Canada Corp, 2000 Argentia Rd, Plaza IV, Suite 302, Mississauga, ON, Canada L5N 1W1 (60 mg of Salinomycin Sodium per kg of feed).

[4] Stafac 44 – Phibro Animal Health Ltd, Regina, SK, Canada S4N 5W5 (11 mg of Virginiamycin per kg of feed).

[5] Probond – Parrheim Foods, 817 48th St east, Saskatoon, SK S7K 0X5.

Table 5. Broiler grower diet composition

	% wheat DDGS inclusion (starter/grower/finisher)					
Ingredient (%)	0/0/0	2.5/5/5	5/10/10	7.5/15/15	10/20/20	12.5/25/25
Wheat	64.71	61.24	57.77	54.29	50.82	47.35
Soybean meal	26.90	25.22	23.54	21.85	20.17	18.49
Wheat DDGS	0.00	5.00	10.00	15.00	20.00	25.00
Canola oil	3.630	3.828	4.026	4.224	4.422	4.620
Limestone	1.650	1.682	1.714	1.746	1.778	1.810
Di-calcium phosphorus	1.240	1.166	1.092	1.018	0.944	0.870
Sodium chloride	0.290	0.272	0.254	0.236	0.218	0.200
DL-Methionine	0.250	0.232	0.214	0.196	0.178	0.160
L-Lysine HCl	0.200	0.238	0.276	0.314	0.352	0.390
L-Threonine	0.100	0.098	0.096	0.094	0.092	0.090
Vitamin-mineral premix[1]	0.500	0.500	0.500	0.500	0.500	0.500
Choline chloride	0.100	0.100	0.100	0.100	0.100	0.100
Avizyme 1302[2]	0.050	0.050	0.050	0.050	0.050	0.050
Biocox[3]	0.050	0.050	0.050	0.050	0.050	0.050
Stafac 44[4]	0.025	0.025	0.025	0.025	0.025	0.025
Probond[5]	0.300	0.300	0.300	0.300	0.300	0.300
Calculated analysis (%)						
AME (kcal/kg)	3,050					3,050
Crude protein	21.64					25.36
Crude fat	5.09					6.58
Calcium	0.90					0.90
Available phosphorus	0.45					0.45
Total phosphorus	0.67					0.69
Sodium	0.18					0.18
Linoleic acid	1.49					1.90

Total/digestible Arg	1.49/1.32	1.43/1.22
Total/digestible Ile	0.84/0.77	0.90/0.75
Total/digestible Leu	1.51/1.35	1.66/1.43
Total/digestible Lys	1.22/1.10	1.30/1.10
Total/digestible Met	0.54/0.52	0.54/0.49
Total/digestible Met&Cys	0.92/0.84	0.99/0.84
Total/digestible Thr	0.83/0.73	0.94/0.73
Total/digestible Val	0.95/0.84	1.07/0.86

[1] Broiler vitamin and mineral premix (NP# 82059025) – DSM Nutritional Products, 395 Waydom Drive, Ayr, On, Canada N0B 1E0. Amount per kg of feed - vitamin A – 11000 IU; vitamin D – 2200 IU; vitamin E – 30 IU; menadione – 2 mg; thiamine – 1.5 mg; riboflavin – 6 mg; pyridoxine – 4 mg; vitamin B_{12} – 0.02 mg; niacin – 60 mg; pantothenic acid – 10 mg; folic acid – 0.6 mg; biotin – 0.15 mg; copper (copper sulphate 25%) – 10 mg; Iron (ferrous sulphate 30%) – 80 mg; Manganese (manganous oxide 60%) – 80 mg; Iodine (calcium iodate 62%) – 0.8 mg; Zinc (zinc oxide 72%) – 80 mg; Selenium 0.3 mg; calcium carbonate – 500 mg; ethoxyquin – 125 mg; wheat middlings – 3.8 g.

[2] Avizyme 1302 – Danisco Animal Nutrition, Box 777, Marlborough, Wiltshire, SN8 1XN United Kingdom (5000 U/g endo-1,4-beta-xylanase EC 3.2.1.8, 1600 U/g subtililsin (protease) EC 3.4.21.62)

[3] Biocox – Alpharma Canada Corp, 2000 Argentia Rd, Plaza IV, Suite 302, Mississauga, ON, Canada L5N 1W1 (60 mg of Salinomycin Sodium per kg of feed).

[4] Stafac 44 – Phibro Animal Health Ltd, Regina, SK, Canada S4N 5W5 (11 mg of Virginiamycin per kg of feed).

[5] Probond – Parrheim Foods, 817 48th St east, Saskatoon, SK S7K 0X5.

Table 6. Broiler finisher diet composition

	% wheat DDGS inclusion (starter/grower/finisher)					
Ingredient (%)	0/0/0	2.5/5/5	5/10/10	7.5/15/15	10/20/20	12.5/25/25
Wheat	73.18	69.41	65.63	61.86	58.08	54.31
Soybean meal	19.60	18.19	16.79	15.38	13.98	12.57
Wheat DDGS	0.00	5.00	10.00	15.00	20.00	25.00
Canola oil	2.660	2.892	3.124	3.356	3.588	3.820
Limestone	1.610	1.640	1.670	1.700	1.730	1.760
Di-calcium phosphorus	1.100	1.024	0.948	0.872	0.796	0.720
Sodium chloride	0.280	0.262	0.244	0.226	0.208	0.190
DL-Methionine	0.210	0.192	0.174	0.156	0.138	0.120
L-Lysine HCl	0.240	0.274	0.308	0.342	0.376	0.410
L-Threonine	0.100	0.096	0.092	0.088	0.084	0.080
Vitamin-mineral premix[1]	0.500	0.500	0.500	0.500	0.500	0.500
Choline chloride	0.100	0.100	0.100	0.100	0.100	0.100
Avizyme 1302[2]	0.050	0.050	0.050	0.050	0.050	0.050
Biocox[3]	0.050	0.050	0.050	0.050	0.050	0.050
Stafac 44[4]	0.025	0.025	0.025	0.025	0.025	0.025
Probond[5]	0.300	0.300	0.300	0.300	0.300	0.300
Calculated analysis (%)						
AME (kcal/kg)	3,050					3,050
Crude protein	19.60					23.55
Crude fat	4.29					5.87
Calcium	0.85					0.85
Available phosphorus	0.42					0.42
Total phosphorus	0.62					0.65
Sodium	0.18					0.18
Linoleic acid	1.38					1.80

Total/digestible Arg	1.14/1.02	1.28/1.07
Total/digestible Ile	0.74/0.67	0.81/0.67
Total/digestible Leu	1.34/1.20	1.51/1.30
Total/digestible Lys	1.07/0.97	1.15/0.97
Total/digestible Met	0.48/0.45	0.48/0.42
Total/digestible Met&Cys	0.83/0.76	0.90/0.76
Total/digestible Thr	0.74/0.65	0.85/0.65
Total/digestible Val	0.84/0.75	0.97/0.79

[1] Broiler vitamin and mineral premix (NP# 82059025) – DSM Nutritional Products, 395 Waydom Drive, Ayr, On, Canada N0B 1E0. Amount per kg of feed - vitamin A – 11000 IU; vitamin D – 2200 IU; vitamin E – 30 IU; menadione – 2 mg; thiamine – 1.5 mg; riboflavin – 6 mg; pyridoxine – 4 mg; vitamin B_{12} – 0.02 mg; niacin – 60 mg; pantothenic acid – 10 mg; folic acid – 0.6 mg; biotin – 0.15 mg; copper (copper sulphate 25%) – 10 mg; Iron (ferrous sulphate 30%) – 80 mg; Manganese (manganous oxide 60%) – 80 mg; Iodine (calcium iodate 62%) – 0.8 mg; Zinc (zinc oxide 72%) – 80 mg; Selenium 0.3 mg; calcium carbonate – 500 mg; ethoxyquin – 125 mg; wheat middlings – 3.8 g.

[2] Avizyme 1302 – Danisco Animal Nutrition, Box 777, Marlborough, Wiltshire, SN8 1XN United Kingdom (5000 U/g endo-1,4-beta-xylanase EC 3.2.1.8, 1600 U/g subtililsin (protease) EC 3.4.21.62)

[3] Biocox – Alpharma Canada Corp, 2000 Argentia Rd, Plaza IV, Suite 302, Mississauga, ON, Canada L5N 1W1 (60 mg of Salinomycin Sodium per kg of feed).

[4] Stafac 44 – Phibro Animal Health Ltd, Regina, SK, Canada S4N 5W5 (11 mg of Virginiamycin per kg of feed).

[5] Probond – Parrheim Foods, 817 48th St east, Saskatoon, SK S7K 0X5.

Table 7. AMEn values for wheat and wheat-corn DDGS as determined using broiler chickens

DDGS Sample Source	Kcal/kg AMEn on DMB	Kcal/kg AMEn 90% DMB
Experiment 1 (CTR0720)		
Wheat – NorAmera July 10th	2999[a]	2699[a]
Wheat – NorAmera Aug 21st	2838[b]	2554[b]
Wheat – NorAmera Sept 22nd	2453[c]	2207[c]
Wheat – Husky May 30th	2807[b]	2526[b]
Wheat/corn – Husky July 27th	2829[b]	2545[b]
Wheat/Corn – Husky Sept 14th	2575[c]	2317[c]
Experiment 2 (CTR0923)		
Wheat – Terra Grain April 28th	2815	2534
Wheat – Terra Grain June 23rd	2881	2594

[a,b,c] Means within a column and experiment with different superscripts are significantly different ($P \leq 0.05$).

Table 8. Apparent ileal amino acid digestibility coefficients of wheat DDGS determined in broiler chickens

Amino acid	Terra Grain April 28th	Terra Grain June 23rd	Terra Grain Unknown date[1]
Ala	0.83	0.82	0.71
Arg	0.87	0.85	0.78
Asp	0.83	0.79	0.53
Cys	0.91	0.85	0.71
Glu	0.86	0.85	0.82
Gly	0.79	0.79	0.69
His	0.85	0.83	0.73
Ile	0.81	0.80	0.69
Leu	0.87	0.86	0.76
Lys	0.88	0.87	0.63
Met	0.92	0.92	0.78
Phe	0.90	0.91	0.84
Pro	0.86	0.86	0.83
Ser	0.82	0.83	0.71
Thr	0.83	0.79	0.65
Val	0.82	0.82	0.71

[1] Determined is a separate experiment.

Table 9. Effect of Wheat DDGS sample and level of diet inclusion on broiler production

	DDGS sample			% wheat DDGS inclusion (starter/grower/finisher)								
	April 2009 "A"	June 2009 "B"	P value	0/0/0	2.5/5/5	5/10/10	7.5/15/15	10/20/20	12.5/25/25	P value	X[1] P value	SEM
W[2] 0d	0.045	0.045	NS	0.044	0.045	0.045	0.045	0.045	0.045	NS	NS	0.00007
W 10d	0.264	0.269	NS	0.263	0.268	0.267	0.271	0.264	0.268	NS	NS	0.0016
W 25d	1.151[b]	1.166[a]	0.032	1.152	1.152	1.152	1.172	1.161	1.161	NS	NS	0.0034
W 35d	2.026	2.021	NS	2.013	2.021	2.025	2.022	2.023	2.036	NS	NS	0.0061
G[3] 0-10d	0.220	0.224	NS	0.218	0.223	0.222	*0.226*	0.219	0.223	NS	NS	0.0016
G 10-25d	0.887	0.897	NS	0.889	0.885	0.885	0.900	0.897	0.893	NS	NS	0.0036
G 25-35d	0.875	0.855	0.093	0.861	0.868	0.873	0.851	0.863	0.875	NS	NS	0.0057
G 0-35d	1.981	1.976	NS	1.968	1.976	1.981	1.977	1.979	1.991	NS	NS	0.0061
C[4] 0-10d	0.260	0.261	NS	0.260	0.260	0.259	0.263	0.258	0.263	NS	NS	0.0010
C 10-25d	1.416	1.428	NS	1.438	1.448	1.421	1.409	1.415	1.400	NS	NS	0.0062
C 25-35d	1.674[a]	1.637[b]	0.030	1.685	1.668	1.662	1.634	1.646	1.640	NS	NS	0.0086
C 0-35d	3.399	3.353	NS	3.424	3.412	3.383	3.341	3.361	3.336	NS	NS	0.0141
E[M5] 0-10	0.848	0.865	NS	0.841	0.862	0.862	0.866	0.854	0.855	ns	NS	0.0058
E[M] 10-25d	0.632	0.635	NS	0.624[bc]	0.621[c]	0.629[abc]	0.640[abc]	0.642[ab]	0.646[a]	0.050	NS	0.0028
E[M] 25-35d	0.526	0.523	NS	0.514	0.524	0.528	0.522	0.526	0.533	0.064	NS	0.0019
E[M] 0-35d	0.597	0.599	NS	0.587[d]	0.593[cd]	0.598[bc]	0.600[abc]	0.603[ab]	0.608[a]	0.0002	NS	0.0015

E[6] 0-10d	0.839	0.856	NS	0.834	0.851	0.854	0.855	0.847	0.844	NS	NS	0.0059
E 10-25d	0.621	0.622	NS	0.612^{bc}	0.602^{c}	0.619^{abc}	0.0637^{a}	0.628^{ab}	0.631^{ab}	0.013	NS	0.0031
E 25-35d	0.506	0.514	NS	0.498	0.511	0.511	0.507	0.510	0.523	NS	NS	0.0028
E 0-35d	0.582^{b}	0.589^{a}	0.044	0.574^{c}	0.578^{bc}	0.585^{abc}	0.591^{a}	0.588^{ab}	0.596^{a}	0.003	NS	0.0018
M[7] 0-10d	2.72	2.66	NS	2.17	3.44	2.17	2.90	2.17	3.26	NS	NS	0.276
M 10-25d	2.60	3.20	NS	3.26^{ab}	4.35^{a}	1.99^{ab}	1.09^{b}	3.26^{ab}	3.44^{ab}	0.029	NS	0.351
M 25-35d	2.23	1.03	0.053	1.63	1.27	1.99	1.81	1.81	1.27	NS	NS	0.250
M 0-35d	7.55	6.88	NS	7.07	9.06	6.16	5.80	7.25	7.97	NS	NS	0.511

[1] X – interaction; [2] W – average body weight (kg); [3] G – average body weight gain (kg); [4] C – average feed consumption (kg); [5] E^{M} – average gain to feed ratio corrected for mortality; [6] E – average gain to feed ratio; [7] M – average % mortality based on chick placement number.

[a,b,c] Means within a main effect with different superscripts are significantly different ($P \leq 0.05$).

Values for mortality (means and SEM) are actual % values while the P value is the result of analysis as a (log+1) transformation.

Table 10. Effect of Wheat DDGS sample and level of diet inclusion the cause of mortality and morbidity (%) from 0 to 35 days of age

	DDGS Source			% wheat DDGS inclusion (starter/grower/finisher)								
	April 2009 "A"	June 2009 "B"	P value	0/0/0	2.5/5/5	5/10/10	7.5/15/15	10/20/20	12.5/25/25	P value	X[1] P value	SEM
Metabolic	1.37	1.15	NS	1.81	1.09	1.63	0.72	0.72	1.63	NS	0.0964	0.214
Skeletal	0.30	0.60	NS	0.36	1.27	0.18	0.54	0.18	0.18	0.0956	NS	0.131
Infectious	4.29	3.93	NS	3.99	4.71	2.90	3.99	4.53	4.53	NS	NS	0.354
Unknown	1.15	0.60	NS	0.72	1.09	1.09	0.36	1.09	0.91	NS	NS	0.177
Other	0.42	0.61	NS	0.18	0.91	0.36	0.18	0.72	0.72	NS	0.0490	0.126

[1] X – interaction.

Values for mortality (means and SEM) are actual % values while the P value is the result of analysis as a (log+1) transformation.

Table 11. Effect of Wheat DDGS sample and level of diet inclusion on litter condition[1]

	DDGS Source			% wheat DDGS inclusion (starter/grower/finisher)								
	April 2009 "A"	June 2009 "B"	P value	0/0/0	2.5/5/5	5/10/10	7.5/15/15	10/20/20	12.5/25/25	P value	X P value	SEM
15 days of age												
Drinker area	2.33	2.21	NS	1.50^{d}	1.63^{cd}	2.13^{bc}	2.50^{ab}	2.88^{a}	3.00^{a}	0.0001	NS	0.114
Door area	1.33	1.29	NS	1.13^{b}	1.13^{b}	1.13^{b}	1.38^{b}	1.38^{b}	1.75^{b}	0.0544	NS	0.068
22 days of age												
Drinker area	2.63	2.67	NS	2.25^{b}	2.13^{b}	2.63^{a}	2.88^{a}	3.00^{a}	3.00^{a}	0.0001	NS	0.070
Door area	1.67	1.58	NS	1.13^{b}	1.25^{b}	1.63^{a}	1.75^{a}	2.00^{a}	2.00^{a}	0.0001	NS	0.071

[1] Subjective scoring of litter condition in two pen locations completed at 15 and 22 days of age – 1 = no packing or fecal buildup; 2 = small non-continuous area; of packing; 3 – 75% or more of area covered by fecal buildup, wet.

[a,b,c,d] Means within a main effect with different superscripts are significantly different ($P \leq 0.05$).

Table 12. Comparison of wheat DDGS amino acid digestibility coefficients from 5 sources

Amino acid	Source 1		Source 2	Source 3					Source 4	Source 5	
	1	2	3	1	2	3	4	5	1	1	2
Ala	0.83	0.82	0.71	0.62	0.61	0.54	0.60	0.67	0.49	0.82	0.81
Arg	0.87	0.85	0.78	0.69	0.68	0.63	0.68	0.73	0.74	--	--
Asp	0.83	0.79	0.53	0.46	0.42	0.33	0.41	0.51	0.39	--	--
Cys	0.91	0.85	0.71	0.65	0.61	0.56	0.60	0.66	0.55	--	--
Glu	0.86	0.85	0.82	0.85	0.83	0.81	0.83	0.85	0.74	--	--
Gly	0.79	0.79	0.69	0.60	0.56	0.50	0.57	0.63	0.50	--	--
His	0.85	0.83	0.73	0.66	0.64	0.57	0.63	0.69	--	0.76	0.74
Ile	0.81	0.80	0.69	0.72	0.69	0.64	0.67	0.72	0.63	0.78	0.76
Leu	0.87	0.86	0.76	0.75	0.73	0.69	0.73	0.77	0.65	0.83	0.81
Lys	0.88	0.87	0.63	0.41	0.35	0.24	0.32	0.46	0.73	0.68	0.64
Met	0.92	0.92	0.78	0.76	0.73	0.69	0.74	0.76	0.70	0.86	0.84
Phe	0.90	0.91	0.84	0.81	0.79	0.76	0.79	0.82	0.71	0.82	0.81
Pro	0.86	0.86	0.83	0.83	0.81	0.78	0.80	0.83	--	--	--
Ser	0.82	0.83	0.71	0.67	0.65	0.62	0.65	0.70	0.62	--	--
Thr	0.83	0.79	0.65	0.57	0.55	0.48	0.54	0.61	0.61	0.72	0.68
Val	0.82	0.82	0.71	0.67	0.65	0.59	0.63	0.70	0.67	0.80	0.76

[1] Source 1 – present study; Source 2 – Classen (unpublished); Source 3 – Bandegan et al (2009) 5 samples; Source 4 – Kluth and Rodehutscord (2010); Source 5 – Oryschak et al. (2010) 1 sample assessed at two levels of dietary inclusion.

e) Conclusions and Recommendations

Wheat DDGS samples from Saskatchewan ethanol manufacturing facilities were studied for their value in broiler diets in this research. Because of changes in the nature of the substrates used for ethanol production, the original research plan was changed and most of the research focused on wheat DDGS from one producer (Terra Grain Fuels). There are a number of conclusions that can be drawn from this research that relate to the potential for wheat DDGS use in broiler diets.

The energy derived from DDGS samples varies according to the chemical constituents of the DDGS samples. The starch (and other digestible carbohydrates), fat and protein are the primary components that affect energy availability in poultry and these were shown to vary in the samples that were examined. The level of starch in samples is a reflection of the

efficiency of ethanol production and companies undoubtedly are striving for maximum conversion of starch to ethanol. Therefore, the higher levels of starch seen in this research are unlikely to be maintained, which will impact AMEn values for poultry. The level of fat and protein in samples is largely dependent on the grain used with higher fat and lower protein in samples with more corn inclusion. Even within wheat DDGS samples, level of protein will be determined by the consistency and level of protein in the substrate grain. The results of this research demonstrate that the AMEn samples can vary within and between production plants and that some caution be used in the AMEn value used in diet formulation. The values determined in this research and used in the subsequent broiler trial were appropriate based on production indices.

Variability in amino acid digestibility is seen in most research with DDGS regardless of the nature of the grain used for fermentation. This is thought to primarily relate to the drying process which can damage protein via a range of mechanisms including Maillard reactions. Plant to plant variation and within plant variation has been shown for corn DDGS. Because of the drying process, the amino acid digestibility of DDGS samples is lower than found for the grain before fermentation. Amino acid digestibility results in this research were higher than expected and do not agree with other reported in the scientific literature (Table 12). However, repeated analysis of key analytical parameters did not change the results. This suggests that the drying process in this plant was very well managed and consistent based on samples taken two months apart. Because of concerns that the values obtained were unusually high, lower digestibility coefficients were used in the broiler trial based on other research on samples from the same plant. Based on performance indices, these values were at the very least not an overestimate and may have less than the true digestibility of the samples. Regardless, caution is justified in regard to the amino acid of wheat DDGS samples. It is likely that the moderate value used in the broiler work is more appropriate in diet formulation. It is important that feed manufacturers understand the potential variability in amino acid digestibility in DDGS samples and provide safety margins that reduce risk of poor performance.

The level of dietary inclusion of wheat DDGS in broiler diets was also studied. It was decided that the upper limit should be lower (12.5%) in the starter diets because of the critical importance of amino acid nutrition during the early part of a broiler's life. The upper limit during the grower and finisher phases, when the highest feed intake occurs, was set at 25%. There was no negative impact of these inclusion levels on the on the performance indices measured. This is higher than some previous research but much of that research failed to consider amino acid digestibility, which is a fatal experimental design flaw. The data presented in this report indicate that higher levels of wheat DDGS can be used in broiler diets, so long as energy and amino acid digestibility are considered.

In conclusion, Wheat DDGS can be used in feeding broilers and add to potential ingredients available in Western Canada. Limits in use are determined by the quality and consistency of the meal as well a potential negative effects on litter quality.

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Financial Statement

A financial statement has been requested from Financial Reporting at the University of Saskatchewan, and will be forwarded directly to ADF when it has been completed.